WATER FOR INDUSTRY

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WATER FOR INDUSTRY

A symposium presented on December 29, 1953
at the Boston Meeting of the
American Association for the Advancement of Science

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Publication No. 45 of the
AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE
Washington, D. C. 1956

Library of Congress Catalog
Card Number 56-11455

PRINTED IN THE UNITED STATES OF AMERICA

Preface

The world is in a race for industrial leadership in which the United States and its allies must maintain pre-eminence as a bulwark against nations seeking to destroy democratic government. The industrial might of the democratic nations is a strong deterrent to further world conflict, for it has been this strength that has decided the outcome of the last two world wars.

Industrial productivity requires material resources and human ingenuity. Of all the material resources, water is used in greater amounts than any other product, and it constitutes in bulk by far the major constituent of all material commodities required by industry. With increasing populations and ever increasing needs for water, competition for the available supplies has become critical in many areas. Industry must regard water as a controlling factor in plant location or expansion. Actual or threatened water shortage is a matter of national concern. Sensing the serious nature of the water problem facing industry in the coming years, and its pertinence not only to national security but also to internal economic stability, the American Association for the Advancement of Science invited a panel of experts to present a symposium on *Water for Industry* at the Annual Meeting of the Association in Boston, December 1953. The symposium was arranged by Section E (Geology and Geography) and cosponsored by Section M (Engineering) and Section P (Industrial Science). Affiliated Associations cosponsoring the symposium were the Geological Society of America, the New England Division of the Association of American Geographers, and the American Geophysical Union. Dr. Thorndike Saville, Dean of the College of Engineering, New York University, served as Chairman of the symposium program.

Government, industry, and conservation groups have recognized the present and impending water problems and have defined several broad concepts of procedure.

Water is a commodity not easily inventoried as to supply and use. It is a renewable resource, variable in abundance in time and place, primarily in response to climate. In large part it is not economically feasible to store water in the quantities required to level the natural variations in supply. It, therefore, becomes necessary, on the one hand, to ascertain as precisely as possible the limitations of nature, and on the other to design for, develop, and use this limited resource with maximum efficiency and equity.

Every known use of water comes into play in its application to industry. As a means of transportation, source of power, avenue of waste disposal, and as an integral part of direct manufacturing processes, water and industry are inseparable. Yet there appear to have been few well-accepted standards followed by industry in its development and use of water. The dependability and quality characteristics of the supply available to many plants were not known when the plants were built, and unless an accounting has been forced by actual or threatened shortage, the requirements for water may even now be only roughly estimated.

The eventual solution to the problem of water for industry will not involve industry alone, for water is a common property which properly serves not one but many users. With few exceptions, our sources of water must more and more provide a sequence of uses, and must be considered as a loan for the period of need by a user, to be returned for additional use with as little reduction in quantity and impairment in quality as is consistent with good conservation controls and techniques.

The attainment of peak efficiency of water use on a national scale will not be easily or quickly realized but not to strive for this husbanding of a vital resource would be as damaging to our national well-being as for a person to ignore a wound and slowly bleed to death.

At present, industry is reported to take nearly one-half of all the water withdrawn for use in the nation. Within a few years the industrial use may double, whereas the increase for other uses will be more moderate. It is relatively certain that our supply of fresh water will remain essentially at its present level for decades to come. It is even more sure that the needs of our people and of our industrial economy for fresh water will increase until complacency, waste, needless pollution, and, above all, ignorance of the problems of water, can no longer be tolerated. Although our total water resources are not decreasing and the overall supply is considerably in excess of present requirements, the readily available supply in numerous areas is inadequate for the rapidly expanding water demands. In such areas water problems and actual shortages pose a threat to the local economy. Perhaps for some regions such an enforced time of reckoning is generations ahead, but surely for others it is already here or just around the corner.

One of the difficulties in preparing an effective, organized defense against the oncoming deficiency of the supply is that knowledge of our water resources is so inadequate for the task. Basic studies of the occurrence and limits of our water resources on a broad scale are being undertaken by the federal government and by several state agencies, but for the most part these data collecting programs lack an adequate interpretive counterpart. There is a large accumulation of hydrologic data, much of which is scattered and incomplete but which, if assembled and applied more effectively to our water problems by competent hydrologists, would greatly increase in usefulness. To date, the effort to apply the available information to the solution of problems has lagged far behind even the inadequate inventorying of water facts. As a consequence many industrial water problems have been needlessly prolonged at the expense both of the industrialist and the inhabitant of industrial areas.

Much can be accomplished even now, by pooling present information. What has been found practical in one process or by one industry can often be applied in like benefit to other conditions. Pollution abatement procedures by one water user makes the task of keeping water clean that much easier for others. A common recognition of a problem, a joining together of the forces of industry, and a concerted application of modern techniques to solve its water problems must be part of industry's contribution to the campaign against water shortages. And it should be further recognized that the longer the delay in concerted action, the more difficult the problems will become and the greater the cost of solution will be.

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Contents

The Available Water Supply

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Until recent years, water has not been a subject of major importance to the nation as a whole. To the contrary, it has been widely accepted in much the same way as air and sunshine, a continuing heritage that fulfills its role in life without reference to a beginning or ending, and as a result it is commonly conceived of as inalienable, free, and everlasting. With consternation it is now being discovered that water, air, and light are not alike in abundance; and water, in the sense that in many places it must undergo expensive handling and treatment before use, for the individual is far from free.

Now as always water is a gift of the skies and the earth, as manifested in a dynamic circuit of moisture with the sun as the source of energy. It is used as needed in that part of its journey that is within reach, and after its temporary service it continues its natural course in unending transport. This marvel of efficient design and convenience would attract little attention if the only needs were those of individuals, but something has happened that requires a critical examination of the hydrologic cycle. Men have become water gluttons, demanding that the natural system provide vast quantities of water at localized sites of their own choosing—a single industrial plant is erected whose machines must be fed as much water as several million people require for personal use. Thus, the hydrologic cycle, efficient as it is, has been found wanting, and must now be analyzed in all aspects, to exploit its more favorable characteristics and to guard against its deficiencies. The water supply, permanent though it may be, is variable in time, in place, and in character, and today's concern is to take stock of these variables as they relate to the industrialized way of life.

From a nationwide standpoint, the United States has been blessed with water. With oceans to the east and west, and the Gulf of Mexico to the south, in a manner of speaking, the country is essentially surrounded by the giant teakettles that generate its continental moisture. With the tremendous fresh water storage of the lakes and streams and the even greater reserves in ground water reservoirs replenished by an average precipitation of about 30 inches a year, the overall picture looks safe enough. Furthermore, no long-run trend toward either a decline or an increase in the overall surface water and ground water resources has been observed within the past few decades of study. This then is the broad picture—the base from which to proceed. In terms of the total area, the supply of water is generous, and that supply appears to be stable over periods of a few generations at least. Are the many water problems that are discussed in the papers or even experienced occasionally in the form of restricted water service only imaginary? Is it possible for the resource to seem adequate overall, but at the same time be insufficient for all uses? A few examples will throw more light on this paradox.

There can be no question but that there is more water than is now being used or is likely to be used for some time to come. Actually, national history reveals that excesses of water have been more vexing to national economy and have caused greater loss of life than have water deficiencies. The chief problem has been that the nation is still largely dependent upon the natural variation in supply, a sort of "here today gone tomorrow" schedule that denies much of the benefit of overall supply. In certain arid or semiarid valleys of southern California, where water is the key to the entire economy of the region, about 88% of all the runoff occurs in 1% of the time, or in a period equivalent to about four days per year. An example of the extreme instability of some streams is the Sweetwater River of San Diego County, California. During the 63-year record, the annual runoff has ranged from 0 to 161,000 acre-feet. Not only do individual streams vary greatly in their flow, but the average yield of drainage basins may differ widely within short distances. In the Olympic Peninsula of Washington, average rainfall changes from over 150 inches a year to about 10 inches a year in a distance of approximately 45 miles. Without reflecting on the blessings of nature, it is obvious that the pattern of the water resources was not designed with needs of modern civilization well in mind.

One of the responsibilities of the Geological Survey is to conduct studies and report on the occurrence, availability and quality of the surface water and ground water resources of the nation. As a part of this responsibility, the Survey has just completed a reconnaissance inventory of municipal water shortages that occurred during the first nine months of 1953, as an aid in effectively programming the Survey's investigations of water resources in water-deficient areas.

It should be clearly recognized that municipal water shortages, although similar in their effect on the water user, may not all have similar causes. To illustrate: Field offices of the Geological Survey, localized in all of the forty-eight states, reported a total of 1,072 municipalities that at some time or other between January 1 and September 30 of 1953 restricted the use of water to all or part of their customers. Of the total shortages, about 55% are attributed to demands exceeding the existing sources of supply, about 4% to limitations in treatment facilities, and 20% to problems of system storage and distribution. The remainder is accounted for by a combination of the above causes.

The municipalities reported were predominantly small, only about 10% being larger than 25,000. For the larger towns and cities only 23% of the shortages are attributed directly to demands exceeding the sources of supply, while 51% were caused by facility deficiencies. It is interesting to note that the results of a questionnaire sent to the large public water systems by the American Water Works Association show quite similar percentages as to type of shortage experienced during 1953. The Association reported that of about 500 of the larger cities questioned, 20% of those that were unable to meet customers' peak demands of midsummer 1953 listed the supply as the difficulty, and 75% listed facility deficiencies as the trouble.

The above figures relate to the kind of shortage, that is, whether due to the sources of water, or otherwise. An evaluation was made also by the Geological Survey of the reasons why these shortages developed. For the 1,072 municipalities about 51% experienced shortages because of population growth and seasonal variation in water use, about 1% because of direct industrial use, and about 34% because of drought or failure of the sources of supply. The remaining shortages were caused by combinations of these conditions.

The year 1953 was marked by trying and costly skirmishes with nature. Certain regions of the country fought droughts, some of several years duration, but at the same time other regions experienced average or above-normal precipitation, and a few localities suffered floods. Agriculture suffered severely over a wide area, even in regions where total runoff and ground water storage was not much below average. Distribution of precipitation was such that soil moisture was deficient during critical periods in the growing season. Municipal water problems appear to have been more numerous than in recent years, but reliable data for comparison are meager. Nevertheless some generalizations are possible.

In spite of severe drought conditions in some parts of the nation, the majority of the public water supply shortages experienced during 1953 were not due primarily to drought or failure of the supply, but to increases in municipal growth, seasonal variation in demand, or industrial expansion. Many of these increases, without doubt, reflected the greater use of water associated with dryness and above average temperature, but the dominant factor was increased use and not decreased supply. A little over one-half of the shortages reported were in the eastern third of the country. Texas and Oklahoma, both drought-stricken areas during 1953, experienced the greatest number of municipal water shortages, but New York, New Jersey, Illinois, and Pennsylvania followed in total number per state, and except for Illinois, drought conditions were not severe, or at least, were of short duration.

The seriousness of water-deficient areas should not be minimized, for they are increasing in number and size, particularly in the West. On the other hand, a great many of the current municipal water problems are not due to inadequacy of source, but to delays in development and to problems of expanding the physical facilities for serving water. Clearly, there are two paramount problems: first, the development of water sources that are of sufficient size and dependability to permit continuing growth, and that afford a reserve for extended emergency conditions; second, to keep ahead of water demands by providing the necessary expansion in system facilities.

The hydrologist is concerned only with the first problem. How can we harmonize a year-round and ever increasing water demand with natural sources, nearly all of which have limitations and many of which undergo great seasonal variation? The most obvious and feasible solution is regulation—regulation in the sense of more even distribution of the supply in time and place. With regulation by storage, together with possible regulation by watershed land management, sources that are adequate in potential can become adequate in fact.

The principle of flow regulation of surface waters is widely understood, but not so widely appreciated. However, the growing concern over water supplies may improve this appreciation. In October 1953, three-fourths of the flow of the Missouri River at Omaha and Kansas City was computed by the Corps of Engineers to be reservoir water released from Ft. Peck Dam in Montana. At Kansas City, river stage without the reservoir releases would have been only 0.2 foot over the absolute minimum required for sanitation and municipal water supply. Other major drainage basins were reported to be similarly benefited. In the Ohio River valley, releases from nine dams contributed measurably toward keeping coal moving and steel mills producing. In the fall of the same year, 80% of the flow of the Mahoning River at Youngstown was being maintained by releases from upstream reservoirs.

Where ideal conditions exist, regulation procedures on small streams might essentially eliminate seasonal fluctuation of flow and except for evaporation losses from reservoirs the supply potential of such streams could be realized. Most streams, however, because of great variations in runoff, topographic conditions, or other reasons, do not offer feasible opportunities for complete regulation, but the flows of nearly all may be regulated to a degree.

Another form of reservoir regulation shows great promise. The quantity of fresh water stored in the rocks beneath the land surface considerably exceeds all the water in streams, lakes, and surface reservoirs. These vast underground reservoirs serve as natural regulators for surface supply, but they, too, can be improved by manipulation. In the west, principally in California, excess surface water is conducted over areas of natural intake to the aquifers, thereby increasing their recharge. Elsewhere, water on a more limited scale is being introduced directly into aquifers by recharge wells and pits. Advantages of such methods include the reduction of surface evaporation losses, relatively inexpensive structures, and the utilization of natural filtration.

Another approach to increasing the available water is that of salvaging some of the natural water losses, and thereby increasing the net supply. Of the average rainfall in the United States of about 30 inches a year, a little over 8 inches runs off through streams. Seventy per cent or more of the water that falls as rain or snow is lost by evaporation and transpiration. This figure includes the losses that result from forest uses, certain land-use practices, evaporation from surface reservoirs, and losses from phreatophytes. This percentage is appreciable and therefore if savings are possible, they would be very worth while.

Along the streams where the water table is high and in the lower parts of many closed basins may be found a group of plants called phreatophytes that habitually grow where they can send their roots down to the water table. The best known of these is the salt cedar common in the West. The action of these plants is twofold. They transpire a great deal of water and thus reduce the amount that is available for other uses. At the same time they concentrate the minerals in the remaining water, thus making it less desirable for downstream use. T. W. Robinson has estimated that the total water use by phreatophytes in the seventeen western states amounts to between 25 and 30 million acre-feet per year. In Nevada, it is believed that it would be practical to salvage about 25% of the water wasted. Better control of plant growth likewise offers an opportunity, as yet almost unexplored, for salvaging water. For example, recent studies by the United States Forest Service at a Colorado experiment station have shown that water yield can be increased permanently up to 25% by the periodic harvesting and thinning of young trees.

Against this background of the occurrence and variation in the basic water supplies, what is the picture of the water needs? The present concern is water for industry and it will be helpful to review briefly what is known of industry's nationwide use of water.

In 1950, the Geological Survey published an estimate of the total industrial withdrawal of water. At that time, the available data indicated a total private industrial withdrawal of about 77 billion gallons a day, only slightly less than the nationwide use of water for irrigation. In addition, approximately one-third to one-half of the water distributed by municipal systems serves industrial users. Without doubt, industrial water use is now the largest component of the nation's water demand, and it is expected to more than double by 1975.

In contrast to the relatively good records of water use maintained by public water supply systems, no broad accounting of industrial water use is kept, and the rate of increase must be based on sample surveys and estimates. Therefore, present concepts of industrial water withdrawal may be considerably in error. For example, the 1950 estimate for Pennsylvania listed industrial use as about 6 billion gallons a day. A more accurate inventory made possible by a state industrial questionnaire for 1951 indicates an industrial withdrawal of about 10 billion gallons a day. Such tremendous water needs by industry might at first glance seem to indicate that industry of the future may be restricted to those relatively few areas containing large untapped water resources. This is not necessarily the case. Most industrial uses are not highly consumptive, so that nearly all the water withdrawn is returned to the streams or ground and except in some coastal areas, becomes available for reuse. Thus, the total diversion from some streams may exceed the flow by several times. Further, a number of the newer plants of some of the large water-using industries have been so designed that the water intake has been very greatly reduced. A new steam electric plant at Amherst, Texas, is reported to use just over one gallon of water per kilowatthour, whereas the commonly accepted water requirement for conventional older plants is 80 gallons per kilowatthour. The Texas plant requires a daily withdrawal from its local wells of only about one million gallons a day, a figure that is well within the range of localized ground water yield in many parts of the country.

In a brief summary, then, some aspects of the available water supply situation are favorable, whereas others are far from reassuring. On the favorable side, our present water use amounts to a low percentage of our potential available supply, and some uses, including that of industry, are not highly consumptive so that repeated use of the resource is possible. A large part of industry's water needs do not require high quality water. Water that would not otherwise serve further useful purpose without expensive treatment, such as sewage effluent and water having high chemical concentrations, can be satisfactorily used for cooling, thereby reserving higher quality water for other uses. Further, the total water resources of the nation have not changed sufficiently within the past hundred years or so to establish clearly a trend toward either increase or decrease, and although such a pattern may exist, it is so moderate that it does not constitute a current problem.

Current research on economically feasible methods of demineralization of saline water to an acceptable level shows promise of making available significant quantities of usable water from moderately saline water. Such an accomplishment would be an actual enlargement of our fresh water supply. Another possibility is that moisture in the atmosphere that would not otherwise be converted to rain over land areas where it can be used may be artificially caused to fall in water-short regions. It is not known as yet how effective one or both methods may be in helping to solve water shortages of the future, but they merit and are receiving careful attention by capable scientists.

The unfavorable aspects are more numerous. If the favorable potential of our surface water is to be put to practical use, extensive application must be made of flow regulation.

Ground water developments have had a topsy-like growth. Although the total storage is very great, ground water problems will continue and will increase in severity until the developments are planned and operated with greater attention to the specific hydrologic factors of each area.

The United States is profligate in its waste of water. The tendency has been to use more than is needed. There are indications that more effective application of irrigation water can be made, with a water saving and without loss in production. The withdrawal needs of industry can be reduced greatly if recirculation is widely applied and improved, to the extent that the location of heavy industry with large-scale cooling requirements may be possible in areas where water supplies are limited.

In the eastern part of the continent, the major water problem is related not to quantity of water, but to maintaining a satisfactory quality of water. Although there are some examples of serious ground water pollution, the chief problem is the pollution of the streams. As there are no widely accepted standards for classifying the degree of water pollution, it is difficult to describe the present conditions, but the United States Public Health Service has estimated that to clean up the nation's streams to a reasonable degree within the next ten years would cost some 9 to 12 billion dollars.

Extended periods of low flow permit the upstream movement of salt water in coastal streams. Thus, in highly industrialized streams such as the Delaware, where fresh water in the reaches near the mouth is at a premium, raising the natural flow by regulation offers a means to restrain the upstream movement of saline water, and in effect increases the supply of fresh water. In many parts of the country, industrial wastes, natural brines, and the salt concentrated through irrigation practices are loading streams at a more or less constant rate so that during low flow, these streams may lose their usefulness for water supply. Where flow regulation is feasible, the mineral concentration of these streams may be maintained at levels permitting continued use for water supply.

The greatest problem of all relates to human timing. On the one hand, there is the tendency to build costly surface water structures and develop ground water supplies before adequate hydrologic data for the best design and operational procedure are available. On the other hand, legal and financial impasses frequently delay needed improvements long after hydrologic characteristics have been satisfactorily determined. These factors of timing may well be the most frequent cause of water problems. It cannot be too strongly emphasized that as the population swells and the per capita water use increases, the store of information about the sources of supply must be enlarged and must be ready so that it can be used effectively when needed. It is not enough to be told that a stream never runs dry. Some day, if not now, it must be known how low a flow to expect, how long a deficient flow will persist on the average, and what the chemical character and suspended sediment load of the stream will be for different discharge rates. The relation to ground water recharge and discharge must also be known, and the stream's flood characteristics must be evaluated. It is highly significant that a large chemical plant in Texas constructed a water intake on the Brazos River so designed that diversion will take place only during flood flow.

The design is such that the water required is obtained and pumped to storage during only 85 to 90 days in the average year, when the chemical quality is good, for during low flows salt water moves in from the Gulf of Mexico. This design and its attendant conservation advantages would be impossible without a considerable period of discharge measurements and quality data for the stream.

It is even more important that ground water developments be based on hydrologic studies, for even visual estimates are not possible. Here, owing to the complex nature of the reservoir rocks and their differing properties of receiving and transmitting water, detailed and often lengthy studies are essential.

All these aids are preliminary to putting water resources to use. Once the hydrologic basis for development is in hand, the water demand must be determined and facilities provided safely in advance of requirements. Water supply engineers have been faced with a distressing number of obstacles in attaining this goal. If there is a lesson to be learned from recent and continuing water problems it is this: the hydrologist, in finding and evaluating the supply, the planners, in determining the requirements, the engineers, in designing the developments, and the lawyers and bankers, in clearing the way, must all take a hand in these problems in logical sequence and with realistic vision. If not, piecemeal emergency type developments will be followed by real trouble. But if water problems are approached with logic and vision, enough of the abundant overall available supply will be where it is wanted, when it is wanted, and the exceptions will stay exceptions and not become the rule.

Water Requirements

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Trends toward Conservation

The growth of American industry has accelerated in the past decade, and this growth has brought with it increased needs for water. As industry sought larger and larger quantities of water and as the competition for existing water supplies grew more intense, there developed an increasing interest in water requirements for industrial establishments and in the possibilities of reducing these water requirements through conservation measures.

The earliest industrial plants were located near streams or bodies of water primarily for reasons of transportation, waste disposal, and water power. To combine these advantages, especially to develop water power, American industrial cities of the period 1800-1850 frequently developed along the "fall line," as at Wilmington, Richmond, and Raleigh. These factors were probably powerful in influencing the growth of cities like Louisville and Minneapolis. River transport took over from water power as a major influence on industrial location in the middle 1800's. Navigation needs played a prominent role in the industrial development of cities like Cincinnati, St. Louis, and New Orleans. By 1900, however, the railroads were providing mass transportation that displaced the river boat. In

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recent years, trucks traveling on a vast network of highways further freed industrial location from its thralldom to the waterways. Although industrial cities are now free to develop at any suitable location, most of the major industrial centers remain located near large streams or lakes.

By 1900, the presence of sufficient water of adequate quality for use in the industrial process was becoming a major consideration in the location of many industrial plants. Earlier water demands had been comparatively small and water-use methods simple. As industry developed along new lines based on chemical and engineering advancements, industrial demand for water spurted upward. Large-scale mass production units such as blast furnaces in steel mills, Fourdrinier paper-making machines, and catalyst crackers in oil refineries demanded extensive use of water for cooling and for handling process materials.

In the period 1900 to 1943 use of fresh water by industry from privately owned sources increased about fourfold. During the same period uses of water for public supply and for irrigation also increased so that the total industrial use of water remained uniformly at about one-fifth of the total water use, according to Picton (1). Estimates by the President's Materials Policy Commission indicate that by 1950 direct industrial use (including some salt water) was about 35 per cent of the total water use in the United States (3). Despite this growing dependence of industry on larger quantities of water, it was still considered an "ubiquitous" resource, and few were concerned over its availability.

At this mid-century both the demand and the supply situation are radically changed. The development of regional industrial complexes has concentrated development in certain areas, which has increased competition for water supply. Today, American society has entered a phase in which industry, agriculture, and public supply needs for water are beginning to conflict. Water, far from being the ubiquitous resource previously so blithely ignored, has now become a more crucial factor limiting plant location in many industries. Recognition of this fact, however, has been both reluctant and incomplete. Industry retains its fetish for wide-open valves, a remnant of days when demands for water were not competitive.

Water, in many plants, is still a taken-for-granted utility, despite the fact that its tonnage exceeds by 250-fold the tonnage of coal, the next major industrial material. There are understandable reasons for this reluctance to be concerned with water use.

Factors Hampering Conservation

In most industrial plants that were built in an era of abundant supplies of water, the equipment has been designed to operate efficiently on large-volume flows. It is very expensive to revise water-using equipment in an existing plant, and it is frequently extremely difficult to show cost savings resulting from capital expenditures for conservation that are as great as the earnings that might be attained more immediately by the investment of the same capital in productive facilities. This force operates to preclude serious attention to utilities such as power, water, or fuel except as they affect costs. With coal costing several dollars per ton and industrial water costing a penny per ton, it is easy to see how water might be ignored. The available techniques for reducing industrial water requirements invariably add to the complexity of construction and operation of the industrial water system. These techniques require careful design, and, for full effectiveness, they need skillful operation.

Possibly the national interest might be served by governmental policies offering financial incentives, such as more rapid tax write-offs, that would encourage water-saving measures, but first it is necessary for government to decide whether the nation needs such a policy.

Owing to the necessity for making limited resources stretch farther, American industry has been developing improved water use methods to get more work out of the available water. By 1949, 40 per cent of the plants checked by the NAM-Conservation Foundation study (5) were reusing water to some extent. The greatest percentage of reuse was reported for the petroleum refining and paper and pulp industries. Perhaps the reuse was stimulated in these and other fields by the desirability of bottling-up or recovering waste products.

There are many examples of industrial establishments that have instituted remarkable water-saving jobs. These plants are of two kinds: (*a*) those built where there was little water to begin with, and (*b*) those that were faced with closure because of growing water shortages. A number of industrial plants built within recent years have made maximal use of water conservation methods through more generous design of heat exchanging devices, through automatic control equipment on water flows, through recycling, through use of the water successively in numerous processes, and through substitution of water of inferior quality for the less available high quality water. These measures have been summarized in the report of Task Group A4.D1 of the American Water Works Association. (4) Conspicuous examples of such savings are the Kaiser Steel Plant at Fontana, California, the Hiram Walker Distillery at Peoria, Illinois, and the Bethlehem Steel Plant at Sparrow's Point, Maryland.

In existing plants, flow control and the elimination of water waste have begun to receive more careful attention. By the installation of automatic shutoff valves, certain firms discovered that substantial water savings (and cost reductions) could be achieved. The substitution of sprays for immersion in industrial rinsing processes also resulted in a reduction in water intake. Other savings were made possible by multiple or successive use, in which water is used in several steps of the industrial process, beginning with those processes having the highest water quality requirements.

In a number of industries where water requirements were large, interest was focused upon techniques for recycling water. Certain of these industries, such as steam power generation, petroleum refining, iron and steel production, were ones that used the largest percentage of their water for cooling or condensing. The water was elevated in temperature but often unchanged in quality. The disposal of warm water in some areas became a problem since it interfered with fish life and with the requirements of other industries and of municipal supplies. Obtaining sufficient new cold water to replace the once-through cooling water also became a problem. To dissipate waste heat while saving water, the use of cooling towers and ponds grew rapidly. Some firms that did not have heat disposal problems, especially those which required treatment of all intake water, found that they could save money by saving water. Others faced the choice of abandoning their installations or conserving.

Unit Water Requirements

The question is often raised: how much water does it take to produce one ton or one pound or one barrel, etc., of product? The American Water Works Association has published some average unit water requirement data, as have other agencies. Although these average figures may be of interest, industry is more concerned with how much water a given plant will need. Because of the possibilities of conserving water, there is often a wide discrepancy between the average water used per unit and the minimum unit requirement based on maximal conservation.

Here are a few characteristic examples of the extent to which water requirements have been reduced by technologically feasible and economically justifiable conservation methods.

Water in a conventional steam power plant is required at the rate of anywhere from 80 to 170 gallons per kilowatthour. With maximum conservation, this requirement can be reduced to only one or two gallons per kilowatthour, a reduction of approximately 99 per cent. An integrated steel plant may require from 30,000 to 60,000 gallons per ton of finished steel. Fontana reduced this requirement to a little over 1,400 gallons per ton. The refining of petroleum, another industry which uses great quantities of water, usually requires 18 to 34 gallons of water per gallon of crude oil refined. One firm succeeded in reducing the requirement to 0.8, and other firms have reported water intakes of one to two gallons of water per gallon of crude oil refined. It may require as much as 14 gallons of water to produce one pound of carbon black, but one plant uses only 0.25 gallon per pound. Table I gives some examples of variance in unit requirements in industrial plants.

It is very difficult to obtain trustworthy unit water requirements for several reasons: (1) records generally are not available; (2) no two plants produce exactly comparable products; (3) an individual plant will usually produce a complex of products and water accounting does not permit suitable breakdowns. Sometimes completely different industrial processes may be used to produce a single product; for example, alcohol may be made by fermentation of grain, or by synthesis from natural gas or petroleum.

The immense variation in unit water requirements also comes about as a result of the great variety of methods for reducing water requirements and the even greater variety of ways in which these methods can be combined. Variations in requirements of the order of 50-fold are found in many fields of industry.

A detailed study and publication of unit water requirements are needed. It is not sufficient to give only average figures. The data should include minimum values obtained from plants doing very thorough conservation jobs, as well as values showing the ranges that occur. Modal and maximum values should also be given. In addition, information on the type of process, special water-handling methods, and other pertinent factors must be included to make the data useful. Partin has made a significant beginning along these lines in his Southern California studies. (2) There was not enough information in the literature to permit a complete presentation of these facts for the cases cited in Table I.

The existence of these variations, and especially the presence of the lower values of water requirements, indicate two things: (*a*) the clear possibility of greatly reducing industrial water requirements, economic factors permitting, and (*b*) the need for technical skill in dealing with complex industrial water supplies.

Conclusion

The needs for industrial water estimated in the President's Materials Policy Commission report are such that industrial use is expected to grow from 35 per cent of the total use in 1950 to 63 per cent of the total national requirements in 1975, despite increases in other uses. The Commission estimates that total water use will nearly double in the 25 years from 1950 to 1975. If there are difficulties in certain locations over water use at present, how much greater will they be as the nation's water requirement doubles?

Inasmuch as accurate data on reuse of water are not available at the present time to cover the nation, it is believed that the estimates of the President's Materials Policy Commission for 1975 are based upon techniques for reuse of water similar to those used at present. The Commission's report points out that "industries could meet a large part of 1975 requirements through recirculation, . . .". In view of the present-day tendency toward incorporating water-saving equipment in new plants, it is believed possible that the industrial water use may not increase in proportion to industrial production, and that future total requirements may be little greater than those of the present. Should it become economically feasible to accelerate the installation of water-saving equipment in existing plants, the total need for industrial water might even be reduced.

The future calls for increasing application of water conservation techniques. Professional people skilled in their use will be required by industry, and it is expected that there will be a greatly expanding field of activity for engineering and chemical specialists in this line of work. Unless the techniques are mastered by a sufficient number of skilled persons, the reduction in industrial unit requirements cannot take place, and our social and economic development may be impeded.

TABLE I

Variance in Unit Industrial Water Requirements

Product or User	Consumption, Gallons Maximum	Average	Minimum	Conservation Technique
Steam power generation, kwhr.	170[1]	80[2]	0.45 (cooling)[3]	Recycling of cooling water through natural draft cooling towers
			1.20 (theoretic)[4]	Recycling through cooling towers
			1.32 (actual)[5]	Recycling through cooling towers
Petroleum refining, gal. crude oil	44.5[6]	18.3[7]	0.8 (actual)[8]	Information insufficient
			1.0 (actual)[8]	Information insufficient
			1.73 (actual)[9]	Complete recirculation through both cooling towers and cooling ponds
Finished steel, tons	65,000[10]	40,000[11]	1,400[12]	Complete recycling through cooling towers; reuse of all flows
			4,000[13]	Recycling through cooling pond

TABLE I (*Continued*)

Product or User	Consumption, Gallons			Conservation Technique
	Maximum	Average	Minimum	
Soaps, edible oils, lb.	7.5[15]		1.57[14]	Recycling through cooling towers and colloidair separation
Carbon black, lb.	14.[15]	4[15]	0.25[15]	Maximum use of air cooling devices
Natural rubber (processing), lb.	6[8]		2.54[8]	Insufficient information
Butadiene, lb.	305[16]	160[7]	13[17]	Theoretical estimate based on complete recycling through cooling towers
Glass containers, tons	667[18]		118[18]	Cooling water recirculated
	507[18]		192[18]	Cooling water recirculated
Automobiles (passenger), units	16,000[19]		12,000[19]	Sprays substituted for immersion rinses
Trucks, buses, units	20,000[19]		15,000[19]	Sprays substituted for immersion rinses

TABLE I (*Continued*)

Source: Data assembled in cooperation with the Department of Geography, University of Illinois.

[1] NAM, *Water in Industry,* 1950, Maximum of firms reporting.

[2] Ohio Water Resources Board.

[3] Farmer, A. E., Why and how of England's big new cooling towers. *Power,* July 1952 (computed).

[4] Powell, S. T., and H. E. Bacon, "Magnitude of Industrial Demand for Process Water," *J. Am. Water Works Assoc., August* 1950 (computed).

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[6] Simonsen, R. N., How four oil refineries use water, *Sewage and Ind. Wastes,* November 1952 (computed for Toledo plant).

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[9] Simonsen, R. N., *op. cit.* (Latonia, Kentucky plant).

[10] Ohio Water Resources Board.

[11] Iron and Steel Institute.

[12] Fontana Division of Kaiser Steel, California (2.8% make-up).

[13] Computed for Provo, Utah, steel plant (6.9% make-up).

[14] Partin, J. L., *op. cit.,* Lever Bros. Two plants, only one conserving water.

[15] Barnes, J. R., Water for industry, Rept. 9, *Resources of Freedom* Vol. 5, Government Printing Office, Washington, 1952. Borger, Texas Plant of Phillips Petroleum used for minimum.

[16] Unpublished communication from E. D. Kelly, director, Office of Synthetic Rubber, Reconstruction Finance Corporation, November 9, 1953. Figure is based on theoretical once-through use.

[17] Kelly, E. D., *op. cit.* Based on theoretical maximum conservation.

[18] Partin, J. L., *op. cit.,* 2 firms before and after conservation.

[19] Unpublished communication from L. A. Danse, General Motors Corporation, October 23, 1953. Experience in General Motors before and after conservation.

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Geographic Distribution of Manufacturing

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Manufacturing industry in the United States is highly localized, much of it being concentrated within a few regions and, within those regions, in or adjacent to metropolitan areas. The demand for industrial water corresponds roughly with the location of manufacturing. This concentration of manufacturing and its water demand may be expected to continue for the foreseeable future, modified in detail but not in major characteristics. Geographic concentration of demand intensifies the supply problem as requirements increasingly exceed amounts locally available. An understanding of the geographic distribution of industry and industrial water use and some of the major factors in that distribution will therefore help to focus the general problem to which this symposium is addressed.

Attempts to show on maps the areal distribution of United States manufacturing in its entirety have had to face the fact that the various statistical units that may be used for such maps do not do equal justice to all kinds of manufacturing. For instance, *value of product* tends to overemphasize the industries in which style or artistic skill is an important ingredient, and to underemphasize those mass-producing a cheap commodity. *Wage earners* overemphasizes industries involving hand assembly of small items and underemphasizes those in which the processes are controlled by engineers but go on pretty

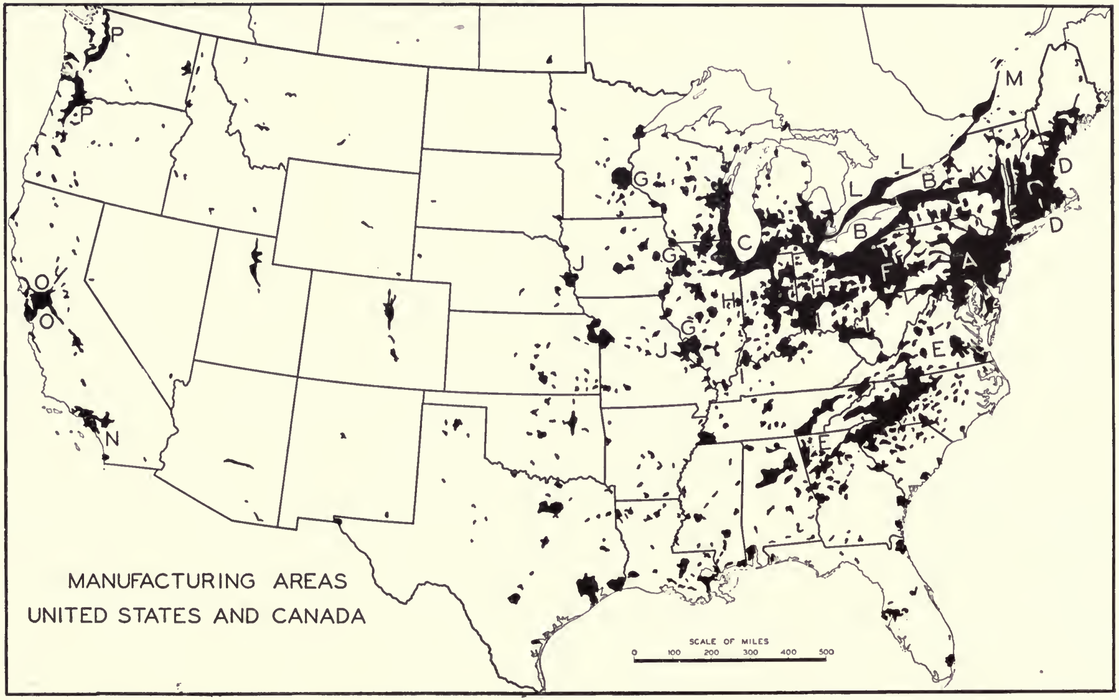

FIG. 1. Areal concentration of manufacturing as measured by combined statistics of wage earners in industry, power used in manufacturing, and value added by manufacturing. Map by Clarence F. Jones (1). Reproduced by permission of the author and publisher from "Areal Distribution of Manufacturing in the United States," in *Economic Geography*, Vol. 14; No. 3, July, 1938.

much by themselves. A combination of items may therefore bring out the essential distribution characteristics better than any single item. Clarence F. Jones published such a map in 1938, based on a combination of wage earners, power used, and value added by manufacture, the last item being the value of product minus the cost of materials, containers, fuel, and purchased electric energy. The map, Figure 1, attests a heavy concentration of manufacturing in a strip east of the Mississippi and north of the Ohio and Potomac, to which Colby called attention as early as 1920 (1). This region has been widely referred to as the "manufacturing belt" ever since the designation was used by Sten de Geer in his classic paper on the subject (2). Since Jones' map was published there have been large increases in manufacturing outside the belt, notably in the western Gulf and Pacific states where, incidentally, water problems are already acute, but at the same time there have been great increases *within* the belt, which continues to be the great area of concentration. Of the new plant capacity covered by "certificates of necessity" issued during the period January 1, 1950, to June 22, 1955, Figure 2, about half is in the manufacturing belt, with another fifth in Louisiana, Texas, and California (3). The concentration is therefore further accentuated, although the rate of increase is somewhat greater in the Texas-Louisiana and California areas, and there was relatively little increase in the New England part of the belt.

Within the manufacturing belt, manufacturing is further concentrated in a series of subregions and in industrial cities. Manufacturing is by its very nature essentially an urban phenomenon, requiring the accessibility, the people, the services, and the markets found in cities. A big city is at once a place of high accessibility, a reservoir of labor, and a market for manufactured products.

Accessibility is the *raison d'être* of cities. They grow up in places of natural accessibility. The efficiency with which cities perform their functions is related both to this natural accessibility and to the development of transportation and communication lines focusing upon them. They are places where

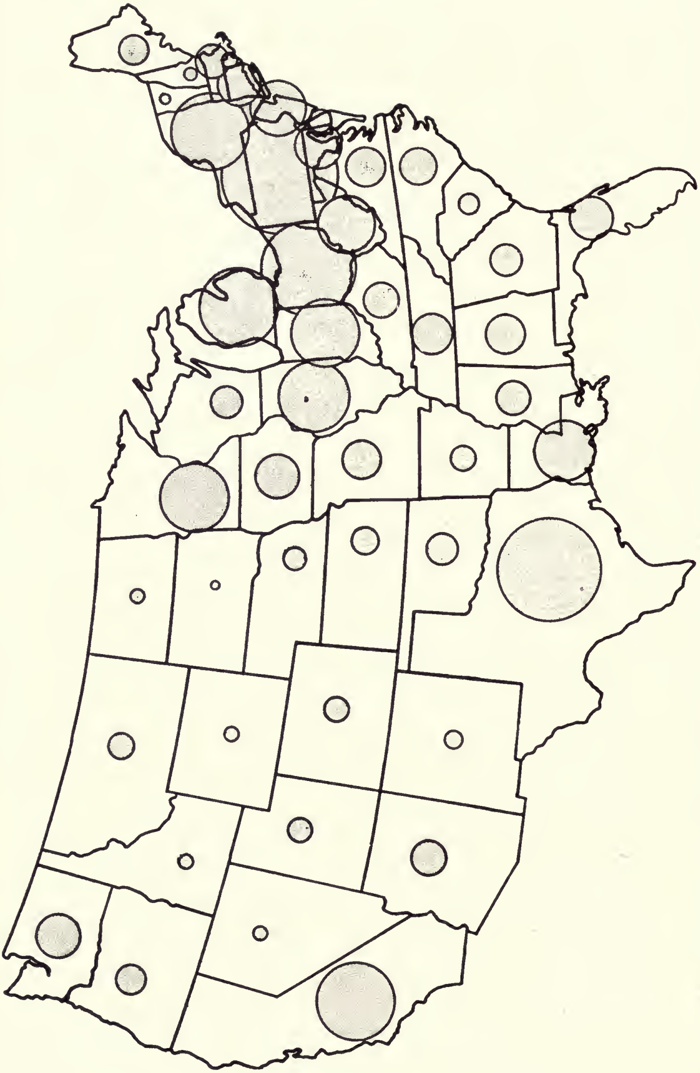

FIG. 2. Investment in industrial defense facilities expansion, January 1950-June 1955. Symbols represent the following amounts, in millions of dollars, in selected states: Pennsylvania, 2,434; New York, 1,100; New Jersey, 513; Maine, 98. U. S. total 30,543. From statistics compiled by Office of Area Development, Department of Commerce.

people (or industries) can reach or come in contact with large numbers of people (or industries) in a short time or at low cost.

Manufacturing requires people for both management and labor, often in great numbers, who have to assemble at plants and disperse to their homes daily. The availability of diverse types of people is greater in large cities, particularly in the case of specialized people who find there the most remunerative or most numerous opportunities to exercise their talent. Agglomeration of people brings both need for and availability of services in great variety and number. Industries as well as people find these services not only convenient but also profitable, and in so doing gain competitive advantage that competitors must either match or compensate for in other ways. The big city is also a big market for the products of industry. The greater the number of ultimate consumers and the greater their purchasing power, the larger the demand for manufactured articles of all kinds. Nearness to consumers means less transportation of product, and usually lower costs and faster delivery. Service industries such as those making parts or performing highly specialized finishing operations find in the big city their natural market, and in so doing make it bigger and more attractive to the industries they serve.

It is worth noting that the manufacturing belt, as pointed out recently by Harris, includes about half of the country's population, about half of the market, "seventy per cent of the labor force, and the sources of supply of most materials and parts directly used in manufacturing" (4).

Manufacturing, although heavily concentrated, is also widely distributed over the United States and is increasing in areas outside the major region of concentration. This is not at all paradoxical. Some of the principal factors that concentrate it also operate to disperse it. This is well illustrated in the case of highly perishable products such as newspapers. The biggest cities produce a share of the newspapers far greater than their share of the population. Rapid transportation facilities with frequent scheduled departures can take the papers, in a short time after they are printed, to readers at considerable distances. The highly developed communication network brings in large amounts of fresh, widely originating news, and the several editions of the papers get it out while it is still fresh. Finally, the big city is itself the locale of the most news. On the other hand, the small city or town newspaper, if sufficiently distant from the big city or off the fast routes, is more accessible to its readers and to local news. Beyond the range where shoppers commonly go to the big city the big newspaper's advertising is increasingly ineffective, and the function of liaison between store and customer is carried out by local papers more readily accessible to both.

As population increases in regions outside the manufacturing belt the regional market increasingly justifies the manufacturing of products for local consumption. Those industries in turn swell the market for other things by their own purchases and by the purchasing power of those employed. The urban-oriented industries are therefore dispersed by some of the very factors that concentrate them.

Some industries are essentially nonurban. These generally involve large scale processing of bulk material of low value. Commonly the raw material is greatly reduced in bulk or weight, or is separated into components that go to different markets, or is perishable. Beet sugar factories illustrate all three points, cotton gins the first two. Rivers that can float pulpwood from a wide drainage basin and concentrate the material at points where falls also provide power offer a favorable combination of advantages in northern coniferous forest areas. Fish product plants are sited where boats can discharge the raw material directly into the factory. Plants separating oil from gas are located in the oil fields or near them. Ore concentration is done at the mines or the points from which the ore is shipped. To be sure, any of these manufacturing establishments may be in or adjacent to a town or city, but the advantage of their special kind of nonurban accessibility is primary in their location.

The total effect of the nonurban oriented industries is noticeable in the overall distribution of manufacturing and is significant in the water problem. In the main, however, manufacturing tends to concentrate in the bigger cities, making them even bigger by doing so, until it becomes predominantly a function of metropolitan areas. The outlook, then, is for industrial concentration, an increasing drain on municipal water systems, and an increasing concern with water as a primary locational factor.

Although the wide variation in water requirement by different industries is independent of variations in the items used as measures of total manufacturing in Figure 1, the total industrial water take shows a heavy concentration in the manufacturing belt (Figures 3 and 4). The two maps of industrial water intake are based on two different estimates, one by the Geological Survey in 1950 (5) and the other by the Bureau of the Census for 1953 (6). Neither set of figures is considered by the collecting agency to be more than an approximation (some state totals were omitted in the Census tables because they did not meet publication standards); they were collected from different sources and are expressed in different units. Although the maps show some differences, which is not to be wondered at, they agree in showing a concentration of industrial water demand exceeding that of manufacturing itself.

Somewhere between two-thirds and three-fourths of the industrial water intake appears to occur in the manufacturing belt; three states, New York, Pennsylvania, and Ohio, alone account for about 40 per cent.

The fact that industrial water use is even more concentrated geographically than manufacturing as a whole appears to be due primarily to the heavy demand of a few classes of industry. Four industry groups took 84 per cent of the 1953 total intake of 11.4 trillion gallons, according to the Census figures. Primary metal industries (essentially blast furnaces and steel mills) took 3.7 trillion gallons, chemicals and allied products, 2.8 trillion, petroleum and coal products (petroleum refineries and coke ovens), 1.9 trillion, and pulp and paper, 1.2 trillion. The 9.6 trillion gallons taken by these industries make them the govern-

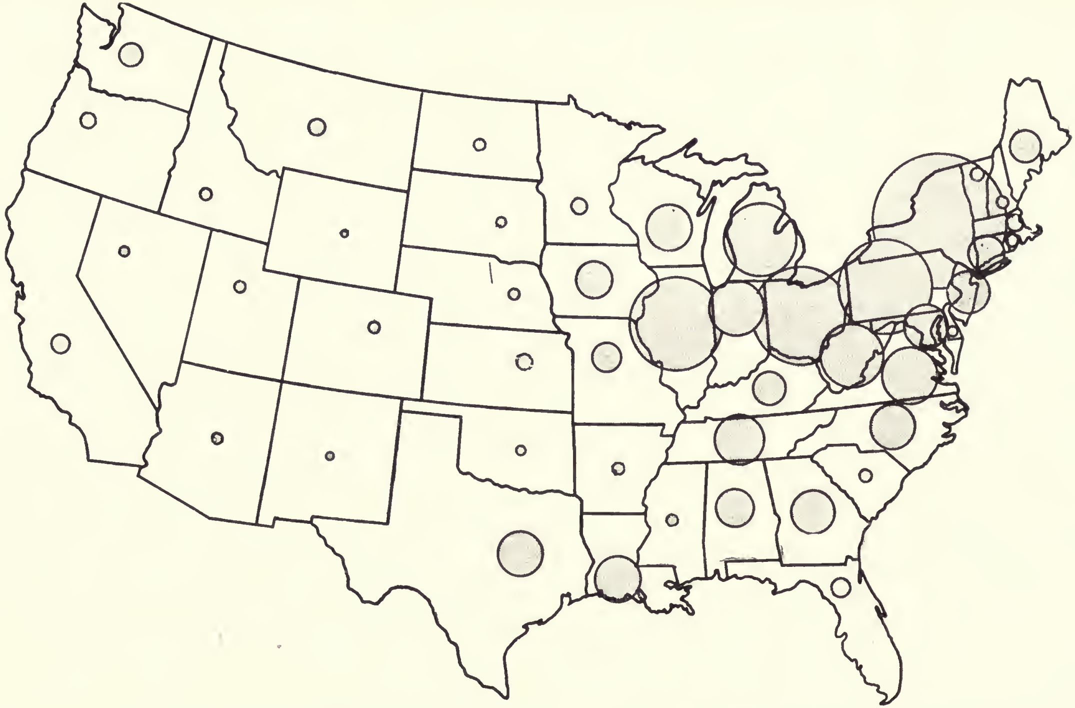

FIG. 3. Industrial water use, 1950. Figures represented by symbols for selected states are, in millions of gallons per day: New York 16,280, Michigan 5,000, Louisiana 1,940, Utah 75. U. S. total 77,216. Amounts are withdrawals and do not take recirculation into account. Some industrial use of municipal water supplies is not included. From estimates by the Geological Survey.

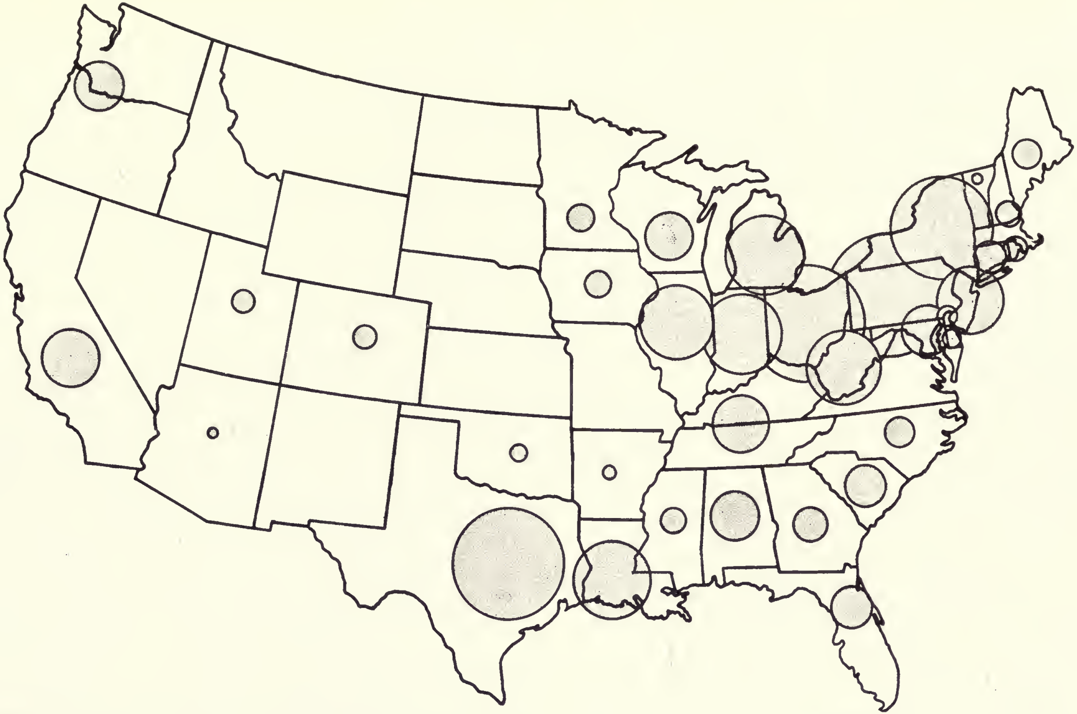

Fig. 4. Water use in manufacturing, 1953. Amounts represented by symbols for selected states are, in billions of gallons for the year: Pennsylvania 1,397, Texas 1,159, Indiana 629, Alabama 207, Arkansas 20. U. S. total 11,430. The figure for Kentucky-Tennessee is the East South Central states total minus Alabama and Mississippi; that for Washington-Oregon is the Pacific states total minus California; that for Oklahoma is the West South Central states total minus Arkansas, Louisiana and Texas. Amounts in states with no symbol could not be derived from regional totals. Central electric stations are not included in the tabulation. From estimates by the Bureau of the Census.

ing factor in the concentration of water demand. In the row of manufacturing belt states from Illinois to New York primary metals industries took from half to two-thirds of the state total; in Michigan they took a third. Pulp and paper took about two-thirds of the water in northern New England and about half in Wisconsin. It was also the principal taker in North Carolina, Georgia, Florida, Mississippi, Arkansas, Minnesota, and Washington. Petroleum refining led in New Jersey, Louisiana, California, and probably Oklahoma. The chemical industries used more than half in Delaware, West Virginia, Kentucky, and Texas.

The heavy metals industries are more concentrated in the manufacturing belt than is manufacturing in general; petroleum refining has three concentration areas, the manufacturing belt, Louisiana-Texas-Oklahoma, and California; pulp and paper industries are concentrated in the coniferous forest areas of northern New England-Lake states, the Gulf South, and Washington; the chemical industry is located principally near industrial markets for the products. The location of the large manufacturing plants typical of the heavy water-using industries is picked only after careful weighing of many factors. Water is one of those factors, and the plant locations are for the most part on bodies of water of sufficient size to satisfy this requirement, commonly by company systems with relatively little draft on municipal supplies.

The 1.9 trillion gallons of intake by other industries is important too. Water is no less vital to those industries, and it is more likely that factors other than water supply were given greatest weight in their location. Some plants have their own surface or well supplies but great numbers of plants in all but the largest size classes rely upon municipal systems, whereas in the heavy water-using industries the characteristically large plants usually require more water than municipal systems are prepared to supply. New York is the only highly industrialized state depending primarily on municipal systems (56 per cent).

In summary, there are two significant aspects of the geographical distribution of manufacturing in relation to water need. First, a relatively small number of large plants in a few industries take the bulk of the water drawn for industry, of the order of 5 per cent of the plants drawing 80 per cent of the water. These plants concentrate demand at a correspondingly small number of points, which makes water a significant factor in the choice of actual site as well as regional location. Secondly, a large number of smaller plants in a great variety of industries take in the aggregate large quantities of water, focusing their demands primarily upon public water systems. These plants are ordinarily located and sited primarily in relation to other factors than water, which may be given little thought until the aggregate take puts serious strain on the public system supplies. Since small plants usually find it less economical to conserve supplies by recirculation, that method of reducing intake is not as readily applicable in the urban-agglomerated industries.

The concentration of demand is one of the primary factors in the industrial water problem. It results from the concentration of manufacturing in large plants, in regions offering the most favorable combination of advantages, and in urban agglomerations. Water will be an increasingly important problem for industry to solve, but the solutions sought will likely be those that will permit capitalizing on the comparative advantages of the more favored regions. Assuming that acceptable solutions will be found, the tendency toward concentration of industry and of industrial water demand may be expected to continue.

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Water and Steel:
Fairless Works Water Supply

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Just across the Delaware River from Trenton, New Jersey, is Morrisville, Pennsylvania, where the Fairless Works, the new plant of United States Steel is located. Inevitably the construction of a large, fully integrated steel plant creates a great many problems which have to be carefully worked out and resolved.

This is especially true, of course, when a pleasant little town like Morrisville, with its quiet way of life and its fine old homes, is suddenly transformed into a great and bustling industrial center. The site of the Fairless Works was selected for many reasons, including commercial considerations and the availability of labor and transportation to receive raw materials and to ship finished products. Among several other important factors was the availability of an adequate water supply. Many months before the first spadeful of earth was turned at the plant site, U. S. Steel engineers were discussing their mutual problems with the people of the Bucks County area, and among the many subjects discussed, water was one of the most important.

To provide the water which is required for a mill the size of the Fairless Works treatment plants have been built which condition the water as it comes out of the Delaware River and then treat it before it is returned to the river. It is of interest to know how water is used in an integrated steel plant and how important a good water supply is to the production of steel. Actually it is so important that the failure of water services would shut down a steel plant in a very few hours. It has been estimated that the American iron and steel industry requires nearly 5 billion gallons of water daily. Water is used as a solvent, as a conveying medium, for the transport of materials and for the disposal of wastes, as a dispersive medium, as a cooling agent, a cleansing agent, and in the production and distribution of heat and power.

Somewhere in the neighborhood of 150 net tons of water are required for every ton of finished steel produced. A little more than 80 per cent of the water used in a steel mill is for cooling purposes, that is, the heat absorbed causes a rise in the temperature of the water of only 5 to 15 degrees Fahrenheit. In the Pittsburgh district for example the temperature of water taken from the rivers may be as low as 33 degrees in the winter or as high as 90 degrees in the summer. This particular range in temperature causes little or no difficulty in steel operations but any appreciable increase would be undesirable.

Water is needed to cool certain parts of blast furnaces where temperatures are high. A blast furnace with a capacity for making a thousand tons of iron daily requires about 11 million gallons of water every 24 hours, and the average temperature rise for all water services on the furnace is about 20 degrees. In some plants water which has been used in blast furnaces is pumped back into the general service mains without cooling. In other plants it is pumped to the top of a huge cooling tower from which it flows slowly to the ground level after giving up heat to the atmosphere.

During steel operations water is also used to remove scale—the oxide of iron which forms on the surface of hot steel—during many rolling operations, and of course for this particular application it is used under high pressure.

One of the largest users of water in a steel plant is the continuous strip mill. A strip mill of the kind at the Fairless Works, for example, uses thousands of gallons each minute to cool rolls, descale hot steel, and remove the scale.

As a general rule, up to 80 per cent of the industrial water used in a steel plant is recirculated and only leakage and evaporation losses, which amount to a small percentage, must be made up. Far more important than its volume would indicate, however, is the so-called welfare water. It amounts to only about 3 per cent of the total volume of water required and is used for drinking, bathing, and sometimes for fire protection. It is, of course, thoroughly treated to insure high purity and, as might be expected, is considerably more costly than the general service water.

This brief statement of the importance of water to steel operations may be supplemented by a detailed explanation of the way in which the water supply problem at the Fairless Works has been met. The scope and magnitude of this problem can be understood a little better, perhaps, by considering that this new plant requires approximately 230 million gallons per day for all services, which amounts to about two-thirds of the daily requirements of a city the size of Philadelphia.

To fill the requirements of the three separate and individual distribution networks at the Fairless Works, namely service water, special process water, potable water, nearly 25 miles of steel, cast iron, and concrete water pipes were laid. These pipes range in size from 6 inches in diameter to 72 inches, and an additional 50 miles or more of pipe, with a diameter of less than 6 inches, were required. For long, straight runs, concrete pipe was used and for several continuous joints and connections, steel pipe was used.

General service uses the greatest volume of water and for this clarified Delaware River water is readily adapted. Much thought was given to obtaining economic operation of the various facilities relating to water supply and disposal, not only in accordance with the demands of the plant itself, but also in accordance with requirements of the various regulatory authorities.

An area on the river bank approximately 2,200 feet long by 1,400 feet wide was allocated for water, sewage, wastes treatment, and pumping installations. The location is central and assured economy in pipeline costs. At this site are located the river water pumping station, river water sedimentation basin, sanitary sewage treatment plant, and industrial wastes treatment plant, together with the central controls building and outdoor substation. This layout within the river site area was especially worked out to bring together in one location equipment and installations which require supervision.

In determining the level of the pump house, several factors, such as maximum flood level in past years, low levels in dry periods, and ice formation in winter, were considered. From data compiled in past years, it was found that the highest flood level of the Delaware River was close to plus 17.0 feet elevation. Therefore, the working level and elevation of the pump motors were fixed at plus 20.0 feet elevation, allowing a safety margin of 3 feet above the maximum flood level.

Depending on conditions in the river, water is taken from five bays at the face of the pump station between elevation minus 7 and plus 7 feet or from lower levels at elevation minus 25.0 through two submerged cribs. Intake pipes from these cribs are 6 feet in diameter. The reason for the two different intakes is to make sure there will be enough water during the winter and during periods of extreme low water. Should large ice chunks impede the water flow over the river bank sills into the intake wells, water can be drawn through the offshore cribs.

After passing through bar racks and conventional traveling screens equipped with automatic cleaning devices, the water is directed either to the low lift or to the service water wells in each of the five bays in the pump house. From there it is pumped to settling basins designed for 80-minute retention. From the settling basins, the service water goes to the points where it is required. Approximately half of the total water pumped from the river is needed at the power house in condensers for turbogenerators and turboblowers, as well as for miscellaneous cooling uses in that area. This condenser water system is fed by two low pressure pipelines. In the event of electrical failure at the river pumping station, there is sufficient storage in the settling basin to maintain operation in this system for approximately two hours. Also, two deep level concrete pipes discharge uncontaminated water from the power house into the river, which is approximately 1,200 feet away. Should a complete electrical failure occur at the river pumping station, standby steam pumps are available.

The other half of the water pumped from the river flows by gravity from the settling basin to pumping station service wells where the service water pumps discharge it into a distribution network system supplying the major plant areas, such as blast furnaces, open hearths, hot mills, and fire plugs. All clean water from this system is returned to the river; the remainder is treated prior to its return to the river or to service water wells for repumping. This service water network has been designed so that it consists of a connected series of loops around each of the major plant areas, thus assuring an uninterrupted supply even if a trunk line were to rupture or break.

Alternatively, the service water supply can be pumped directly from the river by the service pumps, thus providing a longer detention time for the condenser water at the power house. Also, the settling basin can, if necessary, be completely by-passed and the intake pumps can send water directly to the pipes leading to the power house.

Operation of the pumping station, under normal operating conditions, is fully automatic with provisions for manual operation at the discretion of the station operator. Operation of the intake and service water pumps is by pressure or level controls. A valve stem operating device, mounted on wheels, is electrically driven to open and close sluice gates, and hand cranks are provided to guard against power failure. Shock chlorination at intermediate periods of short duration is utilized to prevent slime accumulation or tuberculations in the pipelines and cooling facilities.

Water of high quality for special processes is necessary for use by the Fairless Works sheet and tin mills. Water which has filtered through the sand and gravel beds of the Delaware River already has excellent chemical and bacteriological quality and it is further treated by chlorination to conform to the quality required for special processes. This particular supply of water is obtained by collectors (caissons sunks into the ground with radial projecting pipes to collect water at water strata level) located approximately one mile away from the Sheet and Tin Mill area. To eliminate the possibility of any adulteration, a completely independent distribution network of pipe delivers this water to the locations where it is used.

Suitable pumps provide high pressure where needed in operations. Fire hydrants are spaced on the pipelines and provisions are made for later installation of automatic booster pumps to increase the pressure in areas where the fire hazards may be excessive.

Some of the noncontaminated water is returned to an independent drainage system where recirculation is provided. Unclean water is intercepted by special sewers which discharge it into the treatment facilities where it is treated prior to its being returned to the river.

The potable water supply is the last of the three distribution systems. The supply source for drinking water and sanitary purposes is a ground water well system, which is completely independent of the other two systems. Electrically driven turbine pumps supply three and one-half to five million gallons each day to service approximately 9,000 employees spread over three shifts. Automatic chlorination insures a safe chlorine residual throughout this system. A separate sewage system is provided for the collection, pumping, and treatment of all sanitary wastes from the plant.

To centralize all operations of water supply and disposal, a central controls building houses all electrical equipment and controls, indicating, recording, and totalizing gages and instruments, the central chlorination room, emergency storage house, and the instrument repair and machine shop. A small laboratory equipped for analysis of water, sewage, and industrial waste, and space for filing records is also included in this building.

Because of their interrelation, most of the instrumentation and controls required for water supply, sanitary sewage, and industrial wastes are in a single room. Alarms warn the operator when there is: low or high water in individual pump wells, general power failure, power failure to any individual pump, and low water in the settling basin. Consequently, during any emergency, the operator can by-pass the defective equipment to assure water services to the plant facilities as well as to maintain operation of the various treatment facilities.

Since Fairless Works is an integrated steel plant involving operations from raw materials to finished products, various industrial wastes originate at the different mills. The wastes consist primarily of oils, acids, alkaline solutions, settleable solids, and miscellaneous other wastes. The problem of stream pollution abatement is quite complicated since this plant is located on the Delaware River approximately 30 miles above Philadelphia, which, along with other users, depends on this river for water needs. With full realization of their responsibilities, U. S. Steel's engineers, together with consulting engineering firms, designed treatment facilities which are believed to be unique in the steel industry.

Waste waters containing mill scale, acids, flue dust, and concentrations of oils and greases are treated close to various operations where wastes accumulate. The effluent from the treatment plants is delivered to a terminal treatment plant at the river site for further improvement. This terminal treatment plant services all processed, nonacid waste waters; the final quality is such that it can be discharged into the river or recirculated into the plant water system.

The treatment processes were designed so that wastes are segregated according to their essential characteristics. Also, wastes are combined so that they can be treated most effectively. Thus, all oil and acid wastes are concentrated in one area for treatment close to the operating facilities discharging these wastes.

Waste pickling solution from both batch and continuous pickling operations is pumped or trucked to two large storage tanks lined with rubber and acid-resistant brick. The portion of waste pickling solution not required for treatment is disposed of by trucking to a manufacturer who uses it in the manufacture of his product. Normally, this liquor is removed continuously, leaving the tanks partially empty to provide temporary storage should any breakdown occur in the trucking system. And sufficient lime handling and slaking capacity can neutralize the entire liquor solution if for any reason this becomes necessary.

Because blast furnace flue dust has a different composition from the other industrial wastes and also because the flue dust can be reused, it is treated separately in an area at the blast furnaces. The clarified waters are emptied into the river.

Inasmuch as such an elaborate treatment system is available for industrial wastes, the Fairless Works sanitary wastes posed no great problem. A separate and intricate system of sewers collects sanitary sewage from all sources in the plant and conveys it to a completely separate treatment plant located near the river. The final effluent from this treatment plant is discharged into the Delaware River.

The wastes of the coke plant pose no problem because these wastes are completely segregated in a separate circulatory system. Waste waters are used for quenching coke and, because they are in a separate system, no waste from the coke plant ever enters the river.

At the Fairless Works, U. S. Steel has realized its responsibilities to the surrounding community and by installing the best and most modern equipment for handling water has carried out these responsibilities.

The Treatment and Disposal of Wastes in the Atomic Energy Industry

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The problems related to the requirements and availability of water for the newest American industry, the atomic energy industry, raises problems in an industry whose impact on natural resources is likely to be profound and expanding.

As a newcomer in the American industrial field, this industry recognizes that, in many cases, others have prior rights to use such natural resources as water and minerals. To this situation the industry seeks to adapt itself and its requirements. In selection of plant sites, in contracting for public services, in designing structures and facilities, and in disposal of its wastes, the atomic energy industry is always alert to the interests and rights of others. Its management and staff accept these limitations and seek to abide by them as a new neighbor should. In effect, this is a stimulating challenge to this new industry and one which in the long run should redound to its credit.

Water Supply and Treatment

Because of the very high temperatures that result from nuclear fission, prodigious amounts of water are used for heat exchange in various processes. Therefore, large atomic energy production plants are located where there is an assured source of water. Supply is from both underground and surface sources. Decisions as to sources depend on availability of supply, physical and chemical characteristics of the water, and economics of supply and treatment. Consultation with the U. S. Geological Survey is customary in advance of selection of water supply sources. It is doubtful that any other major industry is required to give as detailed study to its water supply requirements in selecting plant sites and in planning operating and control facilities as does the nuclear energy industry.

In a nuclear reactor, such as those at the Hanford Works (3) in the state of Washington, cooling water in flowing through the facility is exposed to bombardment by neutrons. The quality of the water is then a most important factor because irradiation of certain dissolved or suspended constituents makes them radioactive, and then there is the problem of disposal of the contaminated water. Dissolved compounds which, when irradiated, form isotopes having long half-lives must be removed from water. At least sufficient quantities must be removed to reduce the contamination to a level that creates no serious disposal problem. This calls for (*a*) careful appraisal of the quality of the raw water, (*b*) decisions as to the degree and economics of the treatment to be given the water, (*c*) knowledge of the situation downstream, that is, who might be affected, and (*d*) study of dilution factors in nature of which advantage could be taken, with prudence, so as to lessen the cost of treatment. In meeting its production requirements the atomic energy industry operates some of the largest rapid-sand filtration plants in the country.

If circumstances and design favor a recirculating or closed water system for a nuclear reactor, a very high degree of water purification is generally required, because of continuous exposure to neutrons while the reactor is operating. In such cases complete treatment for demineralization (4) is usually provided. The water is cooled by various well-known methods in outside heat-exchange facilities. A low percentage of make-up water is required to compensate for losses and to hold radioactivity to required levels.

Water-use requirements include those for heat exchange at reactors, gaseous diffusion, chemical processing, and power plants; also for domestic uses, including fire protection. The degree of treatment required depends on the intended use and on the quality of the raw water. Because of higher operating temperatures in some processes, the low-temperature water required by some industries for heat exchange is not always necessary in atomic energy operations. Water used for heat exchange is pumped at high pressures and at very high velocities. Great care is taken in the selection of materials for pipes, pumps, storage tanks, and their accessories to assure continuity of operation and freedom from such problems as corrosion. If corrosion occurs, its products may become radioactive and create operating problems.

Disposal of Wastes

The wastes of the atomic energy industry are both toxic and radioactive. Their disposal in the solid, liquid, and gaseous forms present unique and difficult problems (1). Some of the more important toxic wastes are compounds of beryllium and fluorine; these are treated to avoid subsequent environmental hazards. The radioactive wastes present unusual problems in treatment and disposal and are relatively costly to handle. Waste problems start with the mining of crude ores containing the fissionable material. They continue on to the residual wastes resulting from extraction of product from a mixture of highly radioactive fission products and unspent fuel material after irradiation in a nuclear reactor.

Solid Wastes

Because of their radioactive properties many solid wastes from atomic energy operations cannot be disposed of by methods common to other industries. Certain wastes having short radioactive lives may be held in a restricted place for decay of their activity to a safe level, after which disposal by orthodox methods may be followed. Combustible wastes may be disposed of by incineration, provided (*a*) that provision is made to remove radioactivity from the products of combustion and (*b*) that the ashes are properly disposed of. An incinerator recently developed for the Commission by the Bureau of Mines (2) assures almost complete combustion and provides for cleanup of the gases by an inertial separator and high-efficiency filters. Other incinerators in use have scrubbing facilities, with subsequent problems of disposal of the liquid waste created, as well as disposition of the radioactive ash.

Disposal of solid wastes by land burial and sea disposal is also practiced. Burial grounds are carefully selected with the advice of a geologist. Backfill over radioactive material must be deep enough to prevent hazardous exposures at the surface. Sea disposal, which has its advocates and its critics, is now under special study by the staff of Johns Hopkins University. Radioactive material disposed of at sea is sealed in concrete and the mixture held in steel drums. Disposal is in deep water off the Continental Shelf.

Gaseous Wastes

In the gaseous effluent from an air-cooled reactor radioactive noble gases and iodine are the significant contaminants. Usually they are discharged to high stacks under conditions which provide for dilution in the atmosphere to safe levels. When meteorological conditions do not permit such dilution, these contaminants may be removed by special processes; or the reactor may be shut down entirely or in part, depending on conditions. In the various chemical processes by which product is obtained from irradiated feed material, gaseous effluents that are toxic or radioactive are removed by various methods, including scrubbing, absorption, ion exchange, and filtration.

Knowledge of meteorological conditions at and in the vicinity of these plants is important. This is true in (*a*) selection of sites, (*b*) location of various buildings with respect to one another, (*c*) design of facilities such as air intakes, air-cleaning equipment, and stacks, and (*d*) location of monitoring stations.

The Atomic Energy Commission has a contract with the U. S. Weather Bureau (9) under which surveys have been made of meteorology in the vicinity of most of its plants, and special problems have been studied and reported on. These relate to plant location, design and operation of facilities, construction activities, and the probable air transport of contaminants from normal operations and abnormal ones such as unforeseen accidents.

Liquid Wastes

Liquid wastes from chemical plants separating product from unspent fuel and fission products create the most serious problems in waste disposal. These wastes are potentially hazardous because their levels of activity are high, and because certain of the isotopes will be radioactive for long periods of time—thousands of years. Many, however, have relatively short half-lives, ranging from seconds to days. Some of these radioisotopes, of which strontium-90 is an example, are especially hazardous because of their biologic uptake in the organs and skeleton of man and animals. The characteristics of certain of these wastes present real problems in treatment and disposal.

Permissible levels of radioactivity in air and water, based on a life-time exposure, have been established and are published in Handbook No. 52, National Bureau of Standards. These are conservative limits, and for short periods of exposure they could be exceeded with safety under controlled conditions.

High-level radioactive wastes in any form must either be decontaminated or be held under controlled conditions until they are no longer hazardous. As a result, large volumes are currently being stored in underground tanks pending development of more effective and economical means of reprocessing them. In an effort to reduce volume—for storage is an expensive method—certain liquid wastes are treated by evaporation, which is also a costly process. Radioactive liquid wastes may be decontaminated by use of ion-exchange materials and by coprecipitation methods. Any of these treatments will produce an effluent of lower activity which must eventually be released to nature. One important problem is treatment and disposal of these low-level wastes as effectually and economically as is possible. Since liquid wastes may be released to the ground or to surface waterways, environmental situations at and in the vicinity of the point of disposal must be evaluated. The U. S. Geological Survey (8) has been invited to assist the Division of Engineering of the Atomic Energy Commission in evaluating these problems and to help in the development of solutions of them.

Problems of Underground Disposal of Wastes

One of the environmental problems just mentioned concerns disposal to deep wells. The present general practice of storage of high-level radioactive wastes in steel tanks near the surface is expensive and, despite all precautions, represents on a long-term basis a potential hazard to the environment. A study by Herrington and others (5) indicated a cost of 44 cents a gallon for storage of radioactive waste in tanks, based on a production of 2,000 gallons a day having a radioactive content of 20 curies per liter. For comparison with this figure, the cost of disposal into an abandoned oil well, assumed to be already existent, at a distance of 100 miles from the source of the waste was also computed. This computation indicated a cost of only 7½ cents a gallon for actual disposal into the well, but an additional cost of 51 cents a gallon to transport the waste the 100 miles from the plant to the well site.

It is obvious that, if transportation costs could be avoided, disposal to the ground would be a comparatively inexpensive way of disposing of radioactive waste. A deep well would eliminate the potential hazard of near-surface storage, it would avoid the uncertainties of disposal into the ocean, and it would seemingly eliminate the necessity of further processing of the waste. Wastes have been put into the ground through subsurface cribs at Hanford, and intensive studies have shown that most of the waste has been confined locally and presents no discernible hazard to the environment.

As the use of atomic energy for power increases, and particularly as attempts are made by government or private industry to make nuclear energy competitive with other power sources, the possibility of low-cost disposal of waste to the ground is likely to be examined more and more closely. It is obvious that disposal to wells has many advantages. However, there are limitations on the method which may not be so obvious. Some principles of ground-water movement and of well practice pertinent to such waste disposal are reviewed in the following paragraphs.

In the first place, the construction and condition of the well itself must be known to be adequate. The casing of the well must be in such condition that it protects the potable or otherwise usable waters through which it passes in the same way that upper aquifers are commonly protected from intrusion of oil-field brines. The condition of the casing and construction of the well, including depth and amount of cementing, must be known. Recharging wells, widely used for return of air-conditioning water to aquifers and for repressuring oil fields, rather commonly become clogged. Provision must be made, therefore, that the head in a waste disposal well does not build up unexpectedly, and the radioactive waste find access to aquifers carrying usable water. The waste put into the well must carry no solids in suspension and no materials in solution that might precipitate upon a change in *p*H or other chemical characteristic likely to change underground.

Assuming that no difficulties with regard to the well itself are encountered, the probable course that will be followed by the waste as it moves through the water-bearing formation into which it is injected must be considered. Under the assumption that the waste has a density equal to that of a natural water or brine in the porous bed into which it is injected, the following points should be noted:

1. The waste, if fed continuously, must be considered as moving in a discrete mass essentially undispersed into the surrounding natural liquid. In a short distance from the well it would occupy a space equivalent to that which would normally carry an equal volume of the water or brine in the aquifer. It

cannot be said categorically that no dilution whatever of these wastes would take place. Schlichter (7) and others have implied that the movement of a tracer through sand results in some dispersal of the tracer. However, no laboratory evidence seems to show any dispersal that cannot be explained as molecular or ionic diffusion or as a result of the experimental conditions, and there are theoretical reasons for believing that the mass of foreign liquid would remain essentially intact. At least, as a guiding principle, it must be assumed that no dilution by mixing occurs. If waste were injected into an aquifer intermittently, some dispersion probably would occur. The amount of dispersion would depend in part on the periodicity of the operation.

2. In most sandy aquifers the average rate of movement would be very slow, and in movement through any substantial distance all but a very few of the highly radioactive isotopes would be reduced in activity by many orders of magnitude. Velocities of some inches or perhaps a few feet per day would be expected in most sandy shallow and uncemented aquifers. In consolidated and semiconsolidated sandstones at depth the permeabilities are generally much lower under natural conditions and velocities are probably lower by two or three orders of magnitude, except in those rocks in which movement is largely through fractures. At a rate of travel of 6 inches per day, the activity of 20-year strontium would be reduced by radioactive decay 1 order of magnitude for about every 2.5 miles of travel, and that of 1-year ruthenium 1 order of magnitude for about every 600 feet of travel.

In any actual problem due consideration would be given to the possibilities of movement more rapid than the average through more permeable beds, or through fractures or other geologic irregularities. In many localities these features would be difficult to assess, and might have to be covered by a generous factor of safety.

3. Adsorption and ion exchange undoubtedly would be very effective in slowing down further the movement of radioactive

components in wastes. Practically all clastic sediments have some ion-exchange capacity. Of some three hundred samples tested by the Geological Survey, the lowest exchange capacity found was about ½ milliequivalent per 100 grams, or about 0.5 per cent of the exchange capacity of a pure montmorillonite. Such low-capacity exchange material, characteristic of the most permeable clastic beds through which waste material might move, represents, nevertheless, a very large power of exchange. One cubic foot of such material has an exchange capacity of about ¼ equivalent, or, in terms of strontium, about 10 grams.

In a good aquifer having, say, a permeability of 1,000 gallons a day per square foot and a porosity of about 25 per cent, in which the water is under a hydraulic gradient of 0.002, or 10 feet per mile, about 1 gallon of water per day passes through each square foot of the aquifer. After leaving the area of more rapid movement in the near vicinity of the well, the velocity of the waste would approach the natural velocity of the ground water with which it was moving. Therefore, before going far a waste would encounter a very large quantity of ion-exchange material. The actual amount exchanged or otherwise adsorbed would depend on the concentrations of radioactive and stable ions, the *p*H of the solution, the temperature, and other factors, so that no quantitative predictions could be made without specific knowledge of these factors. However, there can be no doubt that the exchangeable cations, including the radioactive ones, would be drawn out in a slowly moving chromatographic pattern, and that part of the ions of intermediate half-life would travel much more slowly than the containing liquid.

4. In cavernous rocks, notably certain limestones and basalts, many of the generalizations made above with respect to clastic rocks do not apply. Average velocities in well-known aquifers of this type are much higher than in sandy aquifers and, where studied, are of the order of a few tens of feet a day. In addition, the velocities are quite variable from place to place and must be expected to exceed greatly the average locally. Further-

more, the opportunities for ion exchange are, in general, less in such rocks. Hence, disposal into basalts and limestones is basically more hazardous than disposal into clastic rocks.

Wastes from chemical processing plants, in general, are heavy liquids. Normally they would be more dense than the water or brine in a porous bed into which they would be placed, and therefore they would settle to the base of the bed. They would tend to move along the floor of the bed in the direction of dip and, in general, at variance with the direction of the hydraulic gradient of the brine or water in the bed. They would be trapped in any depressions in that floor according to the same principles that Hubbert (6) has elucidated for the hydrodynamic entrapment of oil at the upper contact of the porous bed. It is probable that a considerable quantity of heavy, inert waste could be so trapped in the uneven floors of many water-bearing beds, with no contamination of the water in the upper part of the aquifer. The waste would diffuse into the slowly moving water above it, but most of its liquid in the diffuse zone would also be somewhat heavier than the natural liquid and would find other traps in which to accumulate.

Radioactive wastes, however, are not inert but are generators of heat. If heavy wastes were moved into traps before their radioactive components were adsorbed, the temperature would rise in these traps. It seems probable that most heavy radioactive wastes might cause a convection in the overlying natural liquids that would spread the diluted waste more or less throughout the porous bed. High density of a waste liquid probably would be an advantage in tending to reduce the hazard in case of an accident, but without further data it should not be invoked as an aid in contemplated, deliberate disposal.

In summary, it may be said that in a good many areas and under known conditions the phenomena connected with ground water motion may be used to lessen the hazards incidental to the wastes of an essential industry. However, disposal to the ground is not as easy nor is it a method as generally desirable as it appears at first sight, and it involves a series of phenomena that must be duly considered in every instance where ground disposal is contemplated.

In conclusion, there are many problems ahead of the atomic energy industry in disposal of radioactive wastes to the ground which are challenging to the geologist. The overall solution of the many waste disposal problems of this new industry calls for teamwork of a high order by scientists in many professions.

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Water Supply and Waste Disposal Requirements for Industry

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At no time in history has man's attention been more intensely focused on water supply problems than at present. This condition exists in varying degrees throughout the entire world and is altered only by a balance between supply and demand. Availability of water governs, to a large degree, the expanding economy of practically all peoples. Since there is no universal qualitative or quantitative specification for water requirements in different areas throughout the world, there can be no common solution to such problems.

The history of man from antiquity has been entwined with water supply, and no nation has expanded or, in fact, long survived in the absence of sufficient water to support national groups and development. As an example, recent information unearthed in the ancient city of Babylon has indicated that the city was overrun by savages. They did not know how to prevent silting up of the canals supplying water to the city. As a result of the ensuing water shortage, the people had to leave and the city returned to the desert.

An ample supply of water and means for disposal of wastes are primary requisites of almost all industries. Industrial development in any area is closely related to the fulfillment of these two requirements. It is interesting to look at the figures quoted in the March, 1953, *Journal of the American Water Works*

Association which gives estimated values of the water consumption in the United States in 1950. These are shown on Table I, and it is evident industrial water consumption is exceeded only by irrigation requirements.

TABLE I

WATER USE IN UNITED STATES

Use	Daily Consumption, billion gallons
Municipal, public	14
Industrial, private[a]	81
Rural, farmstead	5
Irrigation	100

[a] Including steam generating condenser requirements.

Never in the experience of this country has industrial growth and development reached such an accelerated tempo as is now occurring. Increased water demands can be attributed in no small measure to research and development which have taken place in recent times. Both during and since World War II, great strides have been made in all fields, especially in electronics, organic synthesis, antibiotics, aviation, and other industries too numerous to mention. It is a natural consequence, therefore, that our expanding economy continuously demands new industrial plants, in addition to plants required to meet the previous needs of basic industries.

There is increasing concern and perhaps hysteria at times regarding water shortages throughout this country. The hysteria is not justified, although it is a fact that owing to overdevelopment of industry and wasteful practices, there are a number of critical water areas. The problem, however, is in many respects not so much a lack of water but a lack of long term intelligent planning.

The location of any industrial plant is influenced by many factors which depend principally on the type of products manufactured and the distribution of these products. No set rule can be formulated which will be applicable to industry's various requirements; however, certain fundamental requirements must be evaluated in order to make possible the intelligent selection of a site and economical design of processes. The present discussion is limited to those factors involving the selection, development, and disposal of water as it influences industry.

Industrial Water Supplies

Surface waters fall either into the classification of lakes or rivers, and the characteristics of waters from these sources vary widely. Under most circumstances, lakes, especially the Great Lakes, are not influenced seriously by drought conditions; whereas rivers, particularly tidal streams, fluctuate considerably in quality and quantity between wet and dry periods. Serious operating difficulties have occurred in many plants because of failure to recognize the importance of fluctuations of the chemical characteristics of flowing streams during wet and dry seasons. In selecting a surface water supply, it is essential to compile all reliable data available regarding river flows over as long a period of time as possible. Too often predictions are based on data covering a limited period.

A change in characteristics of a water supply during extremely dry weather may result in increased operating costs and, more important, may overload the water treating system. The importance of the problem is illustrated by the change in hardness occurring during high and low river flows as shown for the Missouri and the Scioto rivers on Figure 1 and for the Delaware and James rivers on Figure 2. These clearly illustrate the extreme increase in hardness as the flows in these rivers are materially reduced. The change in flow may be accompanied, also, by marked increase in the salinity and the total mineral content of the water. It is apparent that the water treating facilities must include provisions necessary to meet such conditions.

Where plants are located on tidal rivers, especially near the mouths of the streams, the chemical characteristics of the water can be greatly affected by intrusion of salt water. This condi-

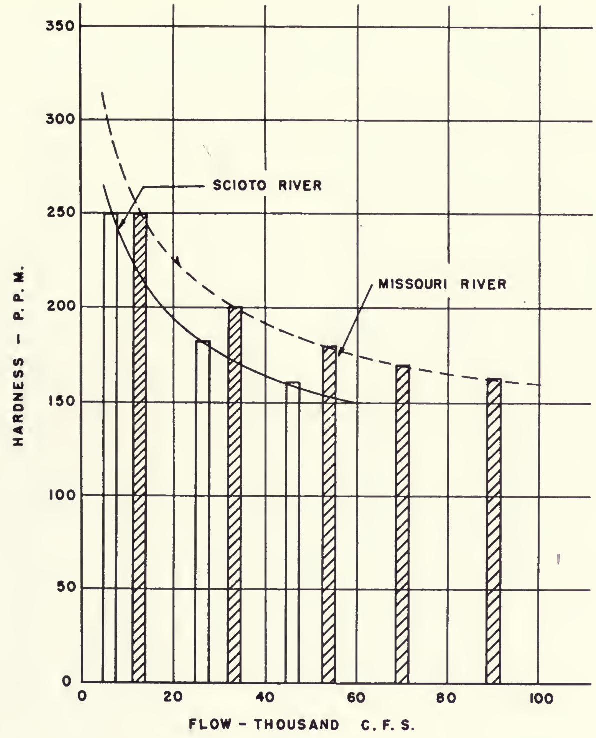

Fig. 1.

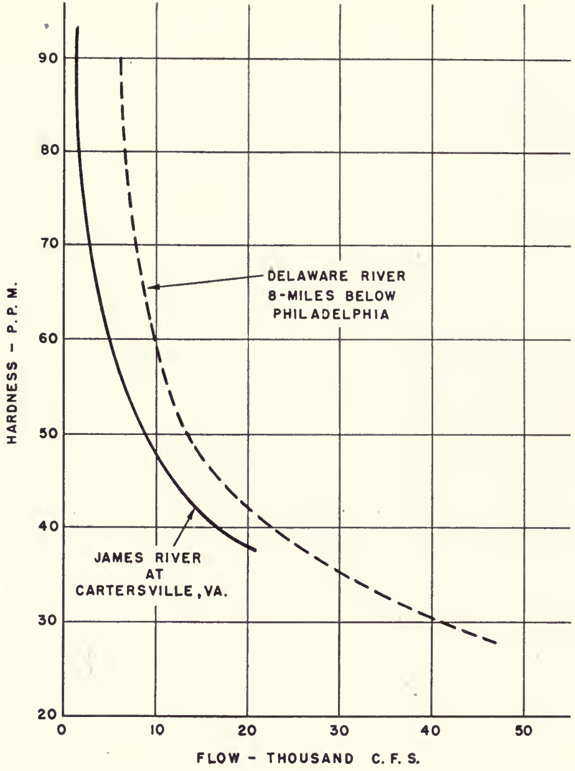

Fig. 2.

Variation of hardness in water in comparison with river flows.

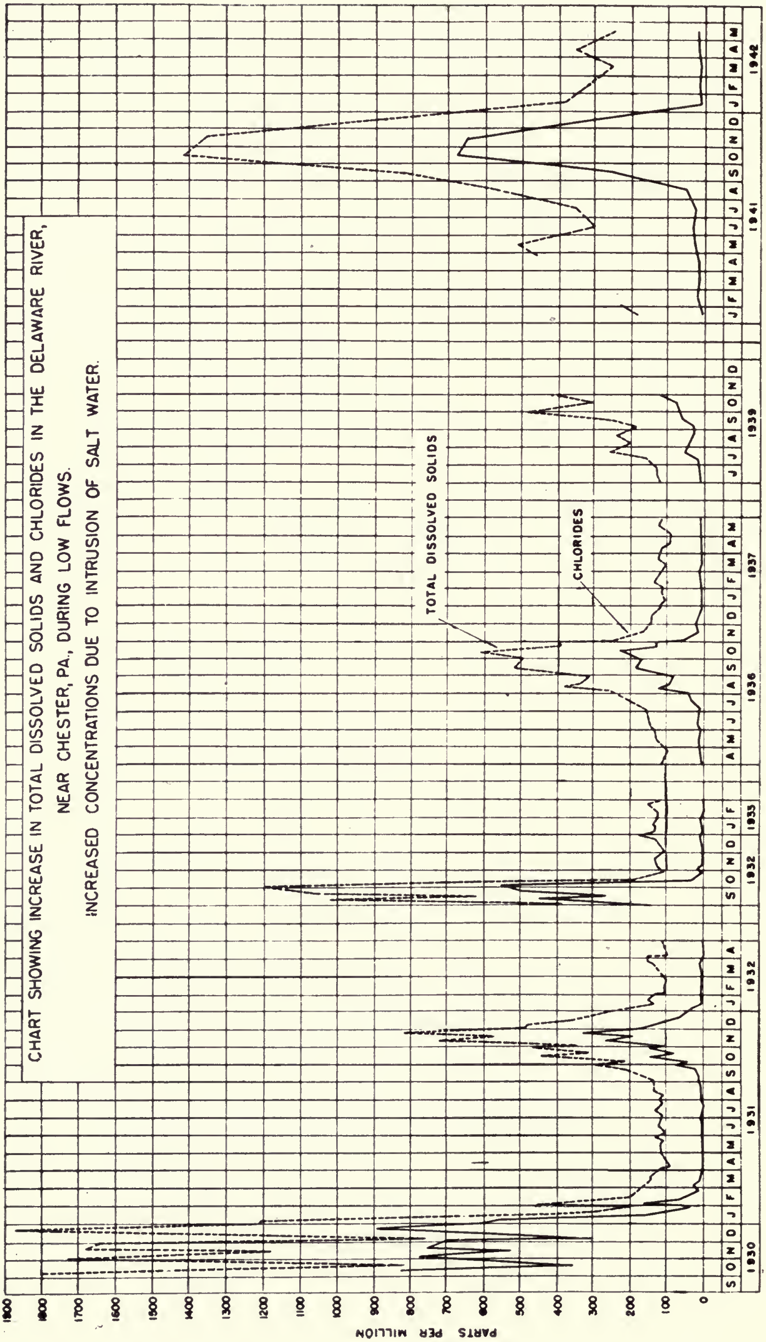
CHART SHOWING INCREASE IN TOTAL DISSOLVED SOLIDS AND CHLORIDES IN THE DELAWARE RIVER,
NEAR CHESTER, PA., DURING LOW FLOWS.
INCREASED CONCENTRATIONS DUE TO INTRUSION OF SALT WATER.
TOTAL DISSOLVED SOLIDS
CHLORIDES
PARTS PER MILLION
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
S O N D J F M A M J J A S O N D J F M A
1930
1931
1932
S O N D J F
1932
1933
A M J J A S O N D J F M A M
1936
1937
J J A S O N D
1939
J F M A M J J A S O N D J F M A M
1941
1942

Fig. 3.

tion occurs because of reduced runoff and resulting low river flows, which limit the ability of the river to keep the salt water out of the streams. As the river flow is reduced, salt water penetrates farther upstream with each high tide, similar to the action of a piston. This condition is illustrated by Figure 3, which shows the rise in the chlorides and total dissolved solids in the Delaware River near Chester, Pennsylvania, during low flows. The record includes the years from 1930 through 1942;

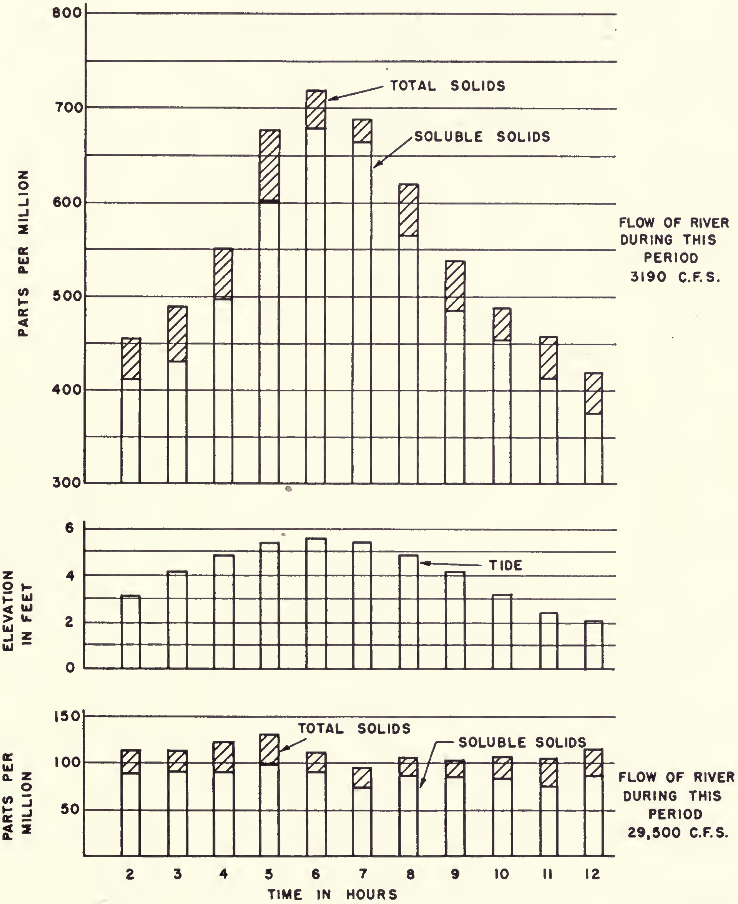

FIG. 4. Effect of reduced stream flow on the total and dissolved solids in the Delaware River.

but the chart is broken to eliminate high flow periods when the chlorides and total solids of the water were low. Figure 4 demonstrates the effect of both changing tide and river flow upon the intrusion of salt water and the resulting quality of the river water.

Average water temperatures and seasonal fluctuations have an enormous effect on surface water value and the usefulness of surface water in many industries. In most localities, the temperature of surface water supplies tends to follow the prevailing atmospheric temperature throughout different seasons of the year. This is illustrated in Table II and Figure 5.

TABLE II

SUMMER TEMPERATURES OF MUNICIPAL WATER SUPPLIES FOR VARIOUS CITIES USING SURFACE WATER SOURCES[a]

Location	Temperature ° F. at Main Outlet			
	June	July	August	September
Atlanta	78.1	83.5	79.5	77.8
Baltimore	61.0	66.0	70.0	64.0
Birmingham	78.0	82.0	81.0	79.0
Boston	68.3	74.3	73.4	69.4
Buffalo	62.0	71.0	73.0	66.0
Chicago	55.4	68.0	69.4	62.5
Cincinnati	76.0	82.0	81.0	77.0
Cleveland	58.0	68.0	73.5	71.0
Detroit	64.0	75.0	74.0	68.0
Kansas City	84.0	93.0	91.0	85.0
Louisville	77.0	82.0	82.0	77.0
Nashville	84.0	88.0	88.0	84.0
New Orleans	86.0	89.0	90.0	90.0
Oakland	59.0	62.0	64.0	64.0
Philadelphia	71.0	79.0	77.0	72.0
Pittsburgh	75.2	80.6	80.6	75.2
Sacramento	70.7	70.7	80.6	77.0
St. Louis	77.0	85.0	83.0	75.0
Washington	43.0	67.0	73.0	75.0

[a] *Heating and Ventilating,* January, 1939; U. S. Department of Commerce publication, April, 1938.

The value of a low cooling water temperature may be placed on a monetary basis or interpreted as equivalent refrigeration tonnage. Not only is the value of industrial water, as a cooling medium, influenced by temperature, but the chemical and bacterial quality of the supply may be affected adversely by increased temperatures. It is interesting to compare the average summer temperature of water supplies in a number of United States cities using well water as shown on Table III and the surface water supplies given on Table II. Similar data are given for various summer months on Figures 6 and 7. It is

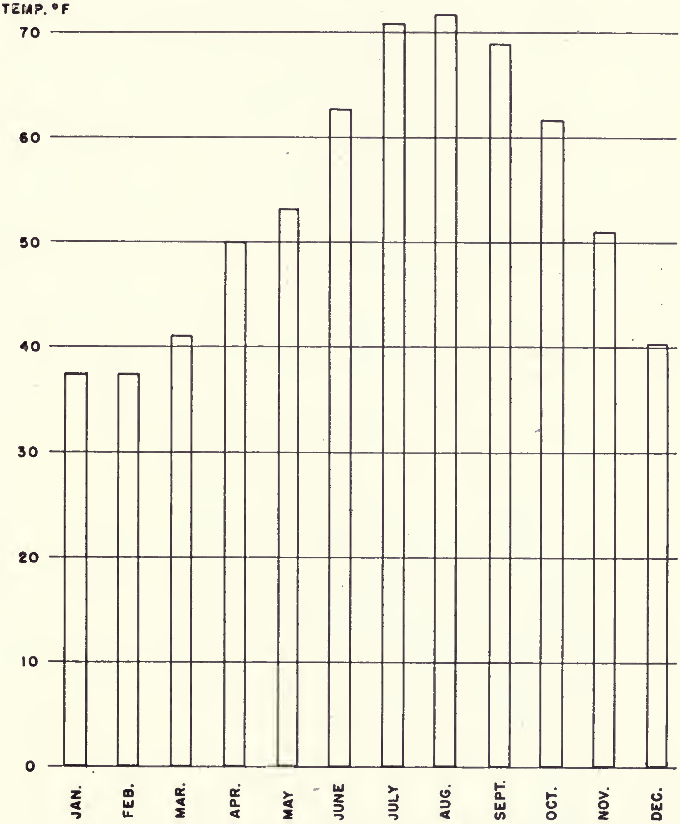

Fig. 5. Two-year averages of daily city water temperatures taken at Toledo, Ohio (1945-1946).

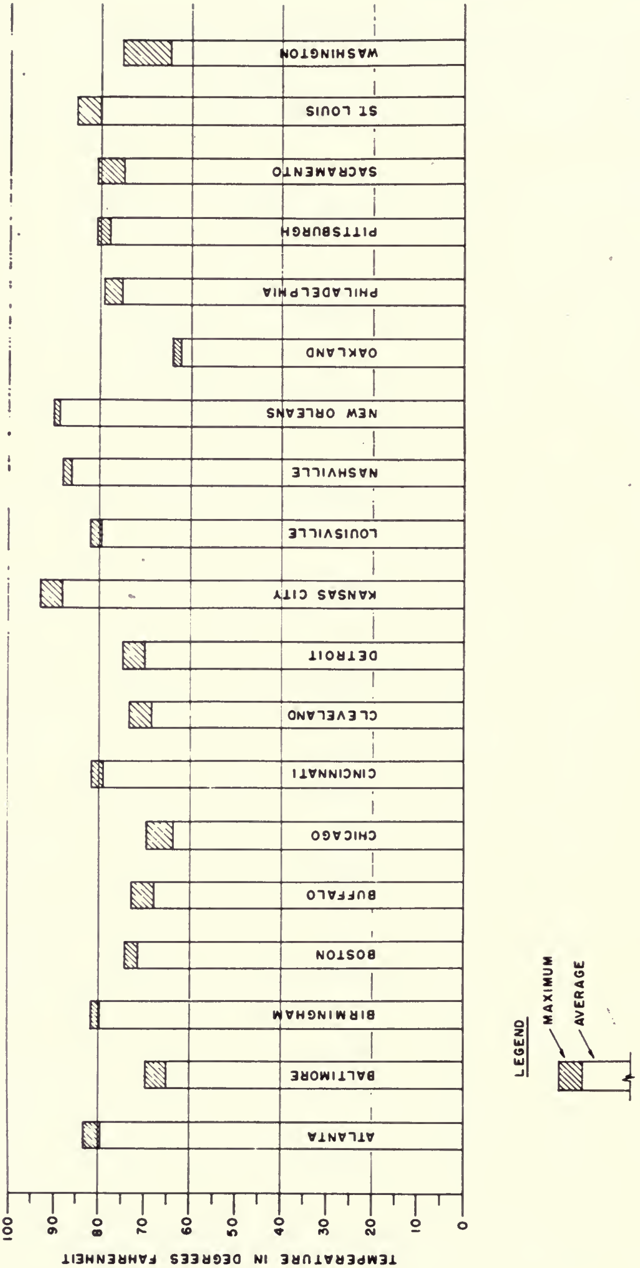

FIG. 6. Average and maximum summer temperatures of surface water supplies in a number of U. S. cities.

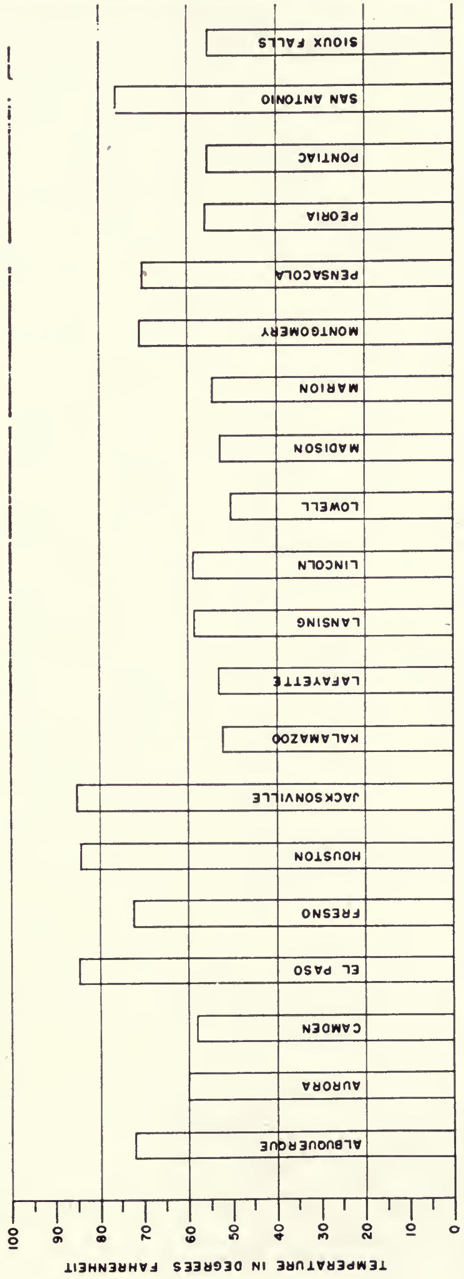

FIG. 7. Average summer temperatures of underground water supplies in a number of U. S. cities. The maximum rise in temperature in these waters above the average is only 1° F.

readily apparent that well water supplies generally have consistently lower temperatures than surface waters during the summer period.

TABLE III

SUMMER TEMPERATURE OF MUNICIPAL WATER SUPPLIES FOR VARIOUS CITIES USING WELLS AS A SOURCE[a]

Location	Temperature ° F. at Main Outlet			
	June	July	August	September
Albuquerque	72.0	72.0	72.0	72.0
Aurora	60.0	60.0	60.0	60.0
Camden	58.0	58.0	58.0	58.0
El Paso	84.0	85.0	85.0	84.0
Fresno	72.0	72.0	72.0	72.0
Houston	84.0	84.0	84.0	84.0
Jacksonville	84.8	86.3	86.7	82.4
Kalamazoo	52.0	52.0	52.0	52.0
Lafayette	53.0	53.0	53.0	53.0
Lansing	57.5	58.0	59.0	59.0
Lincoln	58.0	59.0	59.0	59.0
Lowell	50.0	50.0	50.0	50.0
Madison	53.0	52.0	52.0	53.0
Marion	54.0	54.0	55.0	55.0
Montgomery	70.0	70.0	71.0	71.0
Pensacola	70.0	70.0	70.0	70.0
Peoria	56.0	56.0	56.0	54.0
Pontiac	55.0	55.0	55.0	55.0
San Antonio	76.0	76.0	76.0	76.0
Sioux Falls	55.0	55.0	55.0	55.0

[a] *Heating and Ventilating,* January, 1939; U. S. Department of Commerce publication, April, 1938.

Wide variation in the degree of water treatment required for various locations can be translated into dollar values as affected by many different factors. The conditioning of water for industrial purposes or for domestic use also is affected quite widely by and in proportion to the contamination of the supply.

For some services, underground water is preferable to surface water because of uniformity of mineral content and temperature and freedom from suspended matter and contamination by sanitary and industrial wastes. However, underground water supplies may contain higher concentrations of soluble salts, so that the economics of treating these waters often is a matter of major concern. Thus, regardless of temperature or other desirable characteristics of underground water supplies, this condition may result in preferential use of surface waters or segregation and use of different water sources for different services.

Industry's Specific Water Requirements

Practically all industrial uses of water fall within one or more of the classifications listed in the following groups: (*a*) cooling, (*b*) processing (entering into or contacting products manufactured), (*c*) power generation, (*d*) sanitary services, (*e*) fire protection, (*f*) miscellaneous (air conditioning, washing, etc.).

Of these uses, the demands for cooling water far exceed all others. For example, large electric generating stations may use 500,000 gallons of water per minute, or more, for surface condenser operations.

Sulfite pulp mill's average water demand is approximately 64,000 gallons per ton of product, finished paper 39,000 gallons, soda mill 85,000 gallons, and paper board mill 15,000 gallons per ton.

Oil refinery's average demand for water is 770 gallons per barrel (42 gallons) of product; wool scouring about 1¼ gallons per pound of wool processed, and cane sugar 1,000 gallons per ton.

Making a ton of viscose rayon requires 200,000 gallons. By-product coking takes 3,600 gallons per ton of coal. Soap factories use 500 gallons for every ton of soap turned out. Each ton of smokeless powder requires 50,000 gallons.

What is involved in such large requirements is an integrated regional approach to the development and conservation of our water resources and disposal of byproducts without damage to others.

Selective Uses of Water by Industries

There are so many uses for water in industry that a complete list of such requirements can hardly be described in detail. It would be impossible to present in this paper specific chemical and bacteriological requirements in the great number of industries where water is essential for processing and other uses, but they are as numerous as the industries in our country.

Cooling Water

The largest single use of water by industries is for cooling purposes. The volume and the temperature of the cooling supply are of the greatest importance and can be specifically evaluated on a dollar basis. These requirements take precedence over the quality of the supply, and rightly so; however, water quality cannot be ignored, especially when dissolved salts, gases, or byproducts which are present have an adverse effect on the heat exchange equipment such as shown in Figure 8.

The more important impurities in water which affect its utility for cooling purposes are scale-forming constituents (hardness), suspended matter, dissolved corrosive gases, acids, oil or other organic matter, and slime-forming organisms.

The effect of temperature on the economic value of a water supply is a phase of water engineering of the greatest importance to industries. Recognition of this is reflected in a study of temperatures of industrial water supplies, published by the U. S. Geological Survey in 1925. For many industrial uses the temperature of water is the governing requisite, and the selection of plant sites is based frequently not only on availability and volume of a water supply, but also on its temperature.

A marked increase in the temperature of surface water, above that normally expected, is caused by the discharge of hot or warm wastes or cooling waters into rivers and lakes. In certain densely developed industrial areas this condition becomes pronounced. As an illustration of this, there have been plotted on Figure 9 the mean air temperatures and the corresponding water temperatures of the Mahoning River at Youngstown, Ohio. This river flows through a highly industrialized section, and within a few miles, the river water is reused for cooling water many times by a number of steel

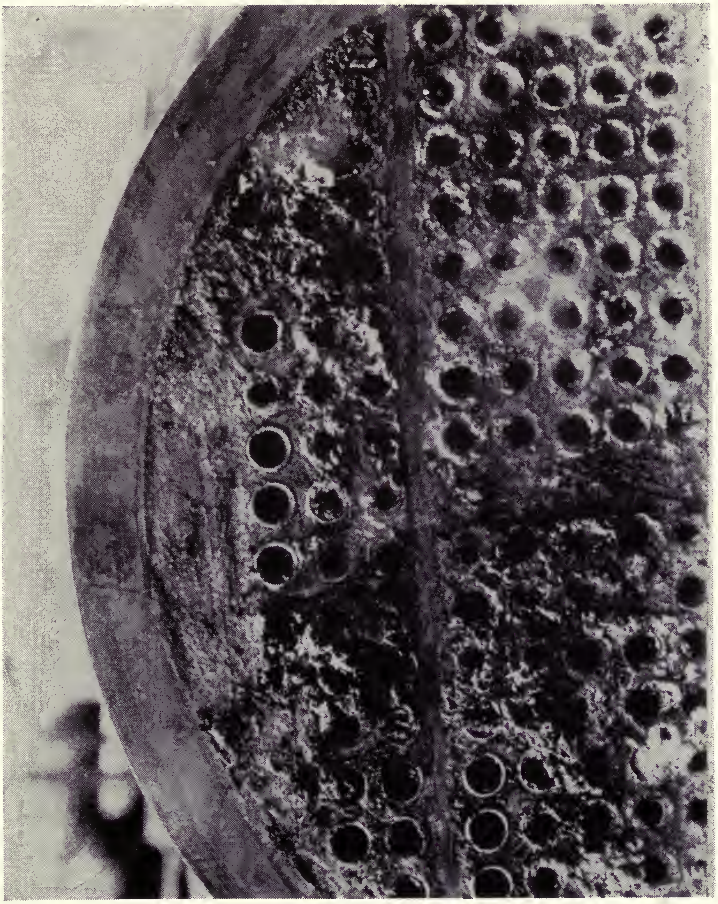

FIG. 8. Deposits on condenser cooled by untreated water.

mills. From these records it is obvious that the thermal value of the water is materially depreciated for cooling purposes, especially when the temperature requirements of certain equipment must be limited to a specific range. Similar conditions exist in other industrial areas, and it is surprising that the problem has not received more attention, since it involves financial losses which can readily be calculated and related to plant efficiency and economy.

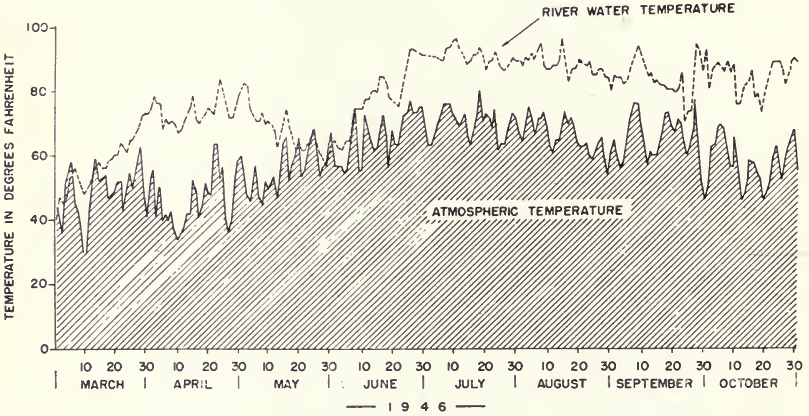

Fig. 9. Relation of air temperature at Youngstown, Ohio, and temperature of the Mahoning River water in the same area.

The great demand for cold water to meet requirements has, in some cases, been responsible for overconcentration of industries in areas where cold underground waters are available. The partial or total exhaustion of such supplies is traceable to these heavy demands. Well failures of considerable magnitude are now occurring in many local areas of the country.

Treatment of Water for Steam Generating Purposes

During the past ten or more years, the specifications for the quality of water for boiler feedwater use have become increasingly exacting. This has been brought about by the installation of boilers designed to operate at high generating rates, which produce steam at greatly increased pressures and temperatures.

At the present time a large number of units are installed which are operating at 1,000 p.s.i. Several boilers are now in service, or are in the process of construction, which will operate up to 2,500 p.s.i. pressure and higher. These conditions require a boiler feedwater of high purity in order to avoid costly maintenance or repairs.

FIG. 10. Tube failure due to analcite scale.

Organic contaminations which inhibit softening reactions are highly objectionable, since the pollutants may reach the boilers in which they decompose and form products which become entrained in the steam, thus resulting in operating and maintenance problems.

Soluble silica is particularly detrimental, for it tends to form dense, hard scale on heating surfaces. This is true even when the silica is present in extremely low concentrations. An example of the results of such scale are shown on Figure 10, which shows a boiler tube that failed due to analcite scale. In the boilers operating at high pressures and temperatures, silica may vaporize with the steam and deposit on the turbine blades interfering with operation as shown in Figure 11. Water treatment required to prevent such losses is being improved continuously but it is also becoming more complex.

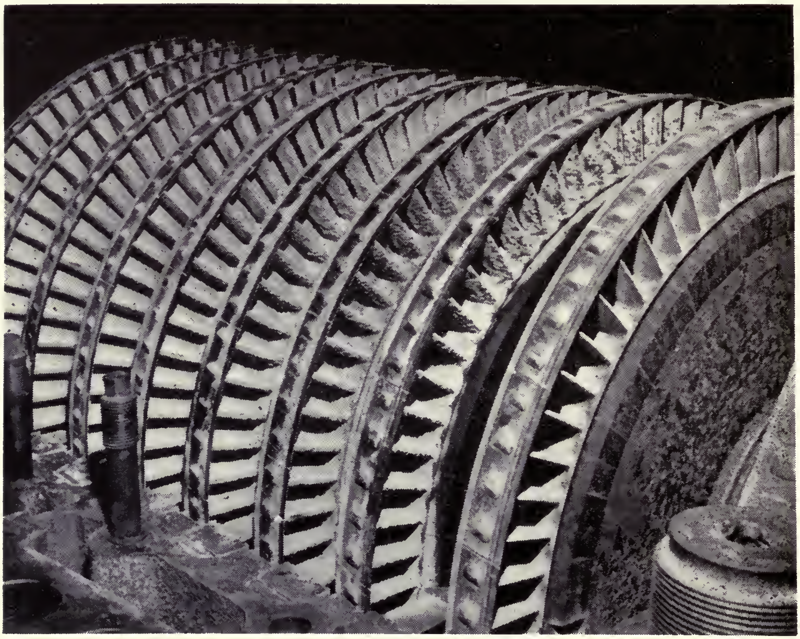

FIG. 11. Silicious deposits on turbine blading.

Effect of Concentration of Industry on Water Consumption and Waste Disposal

It is an undisputed fact that, individually and collectively, we are the most wasteful people in the world. This practice is strongly reflected in our water consumption. The average rate of water consumed in ten European cities, prior to World War II, was 39 gallons per capita per day, while the rate in ten American cities of comparable population was 155 gallons. In Figure 12 is shown a change in consumption for a period from 1900 to 1950 for the cities of Stockholm, Copenhagen, and

Helsinki. The installation of modern kitchens and baths are credited with much of the increased consumption during these years. In a recent analysis of census figures in a number of cities in this country, it was revealed that while the increase of population over a number of years varied from 6 to about 64 per cent, the per cent of increase in water consumption fluctuated in the same cities from 69 to 2,500 per cent.

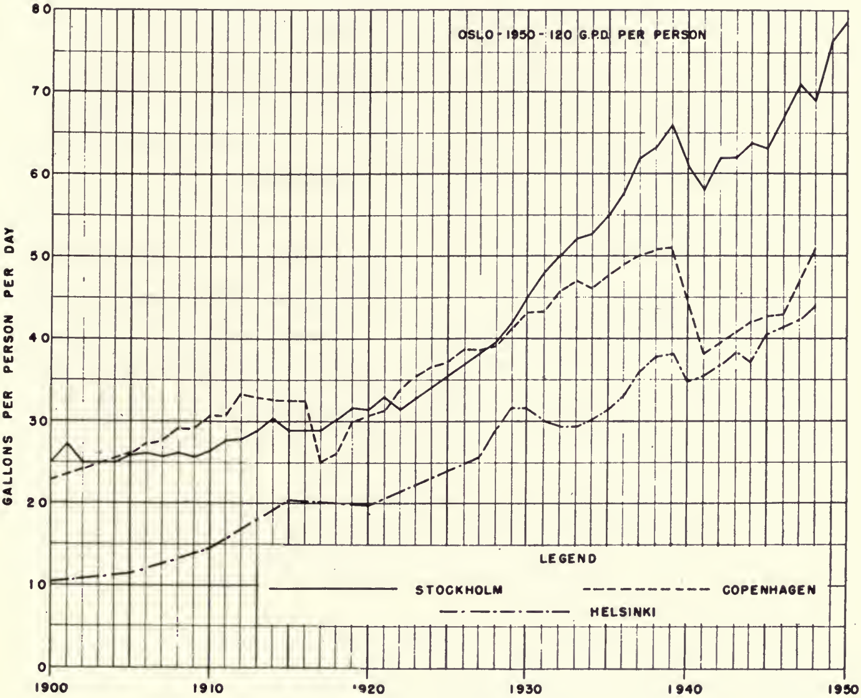

FIG. 12. Increase in the daily per capital consumption of water for the capital cities of the Scandinavian countries (1900-1950).

In the state of Texas, over a fifty-year period, from 1890 to 1940, the population increased 287 per cent; whereas the demand for surface and underground water during the same period rose more than 7,000 per cent. This reflects both industrial concentration and losses recoverable at least in part. Such waste is reflected in many ways other than water used and contributed in no small measure to gross pollution of our waterways by general wasteful practice of products discharged to our streams.

Influence of Stream Pollution on Industrial Water Supplies

The pollution of surface water supply sources has become a problem of major magnitude, and legislative bodies have responded with a variety of control measures. Pollution loading on streams has a direct bearing on the type and design of water conditioning plants and on the investment required for the treating facilities and the cost of operation.

Oil Contamination

Practically all surface waters receiving industrial wastes are contaminated by oil to some degree. In areas where petroleum refineries are located, contamination may be fairly extensive. Oil and grease contaminants are contributed also by vegetable oil processing plants, wool scouring operations, domestic sewage, and other sources.

The free oil present can be fairly readily removed by adequately designed and operated treating systems, but when oil is present as an emulsion or in combined form, it may pass through treatment plants.

The increasing demand for reduction of the amount of oil in waste waters is requiring the installation of oil removal systems not previously considered necessary.

Treatment for breaking emulsions may consist of coagulation with lime and an iron salt, and subsequent removal of de-emulsified and suspended oils by means of clarifiers. It is difficult to establish any maximum limit to the quantity of oil which should be permitted to be discharged into a surface water supply. A fair and workable limit to be imposed on oil content must take into account the local conditions and an evaluation of the capacity of the receiving body of water to destroy or dissipate the oil which will be added.

Plant Location and Design

No study of plant location, as related to water supply, should ignore the pollution contributed to the water supplies under consideration. This has a marked bearing on the selection of the type and design of the water conditioning system required. Further, it is an important factor in the choice of construction materials for all equipment in contact with raw and treated water. Regardless of the many stream pollution control measures, contamination will continue to be a problem.

The type of water purification system and the degree of treatment are governed by specifications for water quality imposed by the process and the products manufactured. Requirements vary widely and each plant should be provided with a system of treatment best suited to meet the local conditions. Often the treatment plant involves extensive and elaborate equipment and may impose a major operating problem. The degree of control that may be required is illustrated by treatment shown by the flow sheet in Figure 13. This diagram indicates that several degrees of treatment are required to furnish supplies of different quality to meet the plant needs. An adequate supply of well water and salt water for cooling would greatly minimize the treatment required.

Sewage Treatment Plant Effluents

The reuse of treated sewage for industrial water requirements or for recharge of aquifers is now receiving much attention as a means for relieving water shortages in some areas. A number of projects of this kind are now in operation and many others are being recommended, some of which are of great magnitude. Undoubtedly, this source of water will solve many new problems but it will require critical evaluation to determine its practical and economic merit.

The industrial use of treated sewage by the Bethlehem Steel Company at the corporation's Sparrows Point mills is an outstanding example of this type of water conservation. The steel

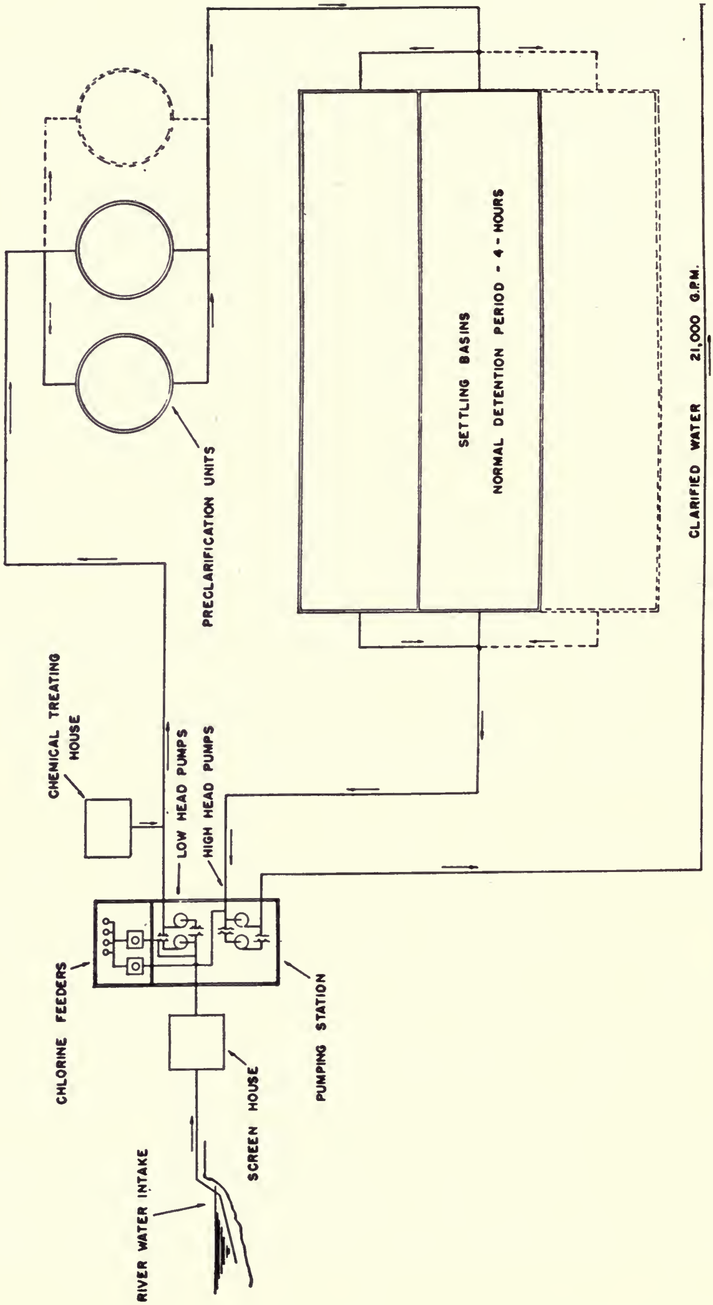

Fig. 13A. Schematic arrangement of equipment for preclarification of raw water and preparation of process water.

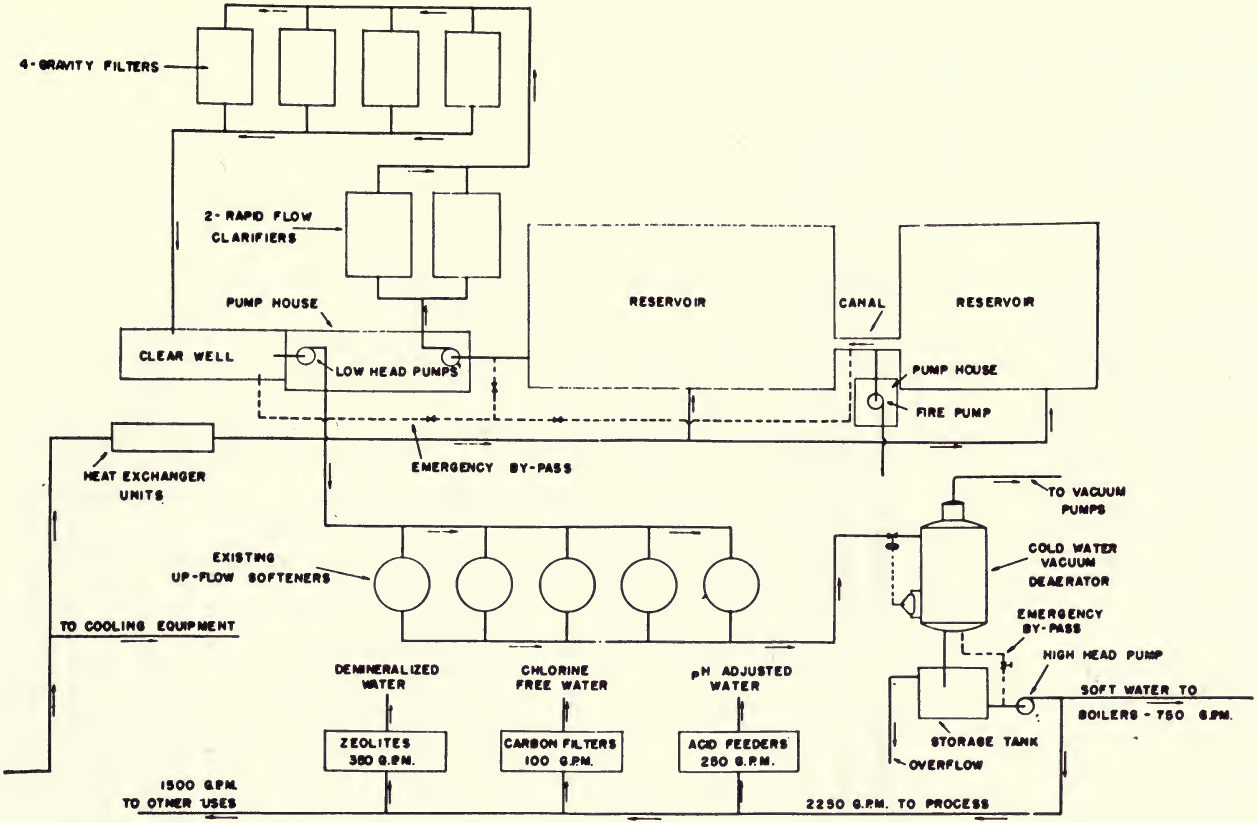

Fig. 13B. Schematic arrangement of equipment for preclarification of raw water and preparation of process water.

company now purchases from the City of Baltimore about 70 million gallons of sewage per day. It is planned to increase the use of sewage until eventually the entire effluent, more than 140 million gallons daily, from the city's treatment plant will be utilized. Estimates for the year 1946 show an average cost of 1.73 cents per 1,000 gallons, exclusive of interest and amortization on the company's investment.

Industrial Waste Treatment

In many cases the satisfactory solution of the industrial waste problem involves chemical engineering principles rather than sanitary and biological processes. Plans for final treatment of plant wastes should be made only after every resource has been exhausted for preventing loss of valuable materials or for recovering these materials before they enter the main sewerage system, or are discharged to the waterway.

The reuse or recovery of waste within operational areas and before release to the plant sewerage system is frequently discussed in academic terms but is too infrequently practiced in industrial plants. In some cases established customs are difficult to overcome; in others, departmental rather than overall costs govern.

Local conditions vary so greatly that no course of action will consistently assure a well-balanced plan for treating industrial wastes, but certain fundamental steps can usually be applied to yield good results. Separation of contaminated waters from clean waters is frequently a necessity. Separate sewerage systems for wastes and storm waters facilitate recovery or treatment and usually justify the expense. Closed systems offer attractive possibilities for recovery or removal of materials which are detrimental to the streams, which can be reused, or which have sales value elsewhere. When treatment costs can be segregated and charged to departments in which the wastes originate, the ingenuity and resourcefulness of the plant superintendents can be depended upon to better conditions.

If the condition of our streams is to be improved, management must revalue the importance of recovery and treatment of wastes and give this phase of manufacturing a rank commensurate with production itself. Wise industrial management in many new plants now considers a process incomplete until the waste disposal problems have been solved satisfactorily.

Management must shortly come to realize that the cost of waste treatment works and their operation is a specified item in the pricing of finished products. Full evaluation of such operations must be included in all cost accounting structures.

Legal Regulations and Government Responsibility

Administrative bodies empowered by law to correct stream pollution abuses have a great responsibility to adjudicate equitably in the interests of all. Unfortunately, there is and can be no simple rule that can equitably coordinate the divergent viewpoints held by different groups. Many administrators are adamant in their requirements, insisting on complete treatment of industrial wastes without giving any credit whatever to the diluting effect of the receiving body of water. In some instances, such inflexible demands may be justified. It is our opinion that in other instances where there are ample volumes of water for adequate dilution of wastes, without any objectionable degradation of the receiving body of water, these severe requirements are unreasonable and economically unsound. Further, we do not believe that any rule or regulation can be established for a given area which will be a permanent solution of the problem, and regulations must be adjusted and modified from time to time as changing conditions in the stream make necessary.

Summary

Since time immemorial, the availability of water has determined where man would build his civilization. Today water is of even greater importance because of the insatiable needs of our expanding industrial economy. Already local shortages have been created, making it more and more important to use, reuse, and conserve one of our greatest raw material assets—water.

Industrial requirements are so all inclusive it is necessary to consider the effects of river flows, drought conditions, salt water infiltration and temperatures in selecting water treating equipment for surface supplies. Underground resources, on the other hand, show less fluctuation in quality and temperature but may involve excessive operating costs and, due to excessive concentration of industry in small areas, may deplete the aquifers and may make necessary the search for means to replace or conserve these supplies.

Conservation may take the form of reuse in the plant, use of sewage treated water, treatment of industrial wastes, and cleanup of our streams.

The need for cleaning up our natural watercourses has been perceived slowly in the past and stream pollution correction in many areas has been haphazard and disorganized. This condition is slowly disappearing and public opinion against continued degradation of coastal and inland waterways is gathering momentum. It is timely to pause for reflection to avoid ill-advised legislation and unsound programs from pressure groups which, although sincere in their motives, are often swept away by their zeal.

Effective cleanup of our streams involves a threefold program: (*a*) comprehensive understanding of the problems by both industrial and regulatory groups; (*b*) avoidance of compulsory orders to install treatment systems within specified time limits, without adequate information necessary for satisfactory design of the treatment works; (*c*) conscientious effort by industry to reduce wastage within plants to the irreducible minimum.

Antipollution Legislation and Technical Problems in Water Pollution Abatement

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Water pollution has existed for years. It is an insidious sort of thing which does not hit really hard until it is well established in its position of making water supplies difficult to handle and of destroying the usefulness of many streams. Since the turn of the century the severity of the water pollution problem has twice been increased very seriously, both quantitatively and qualitatively. World Wars I and II caused the increase. During these periods there was no advantage in saving the waterways and losing the wars. Industry and population had to go all out to win the wars and consequently the wastes of industry and population increased manyfold; also, the obnoxious characteristics of these wastes were greatly expanded. Further, industrial activity spread to many new sections of the country. New concentrations of population were established and older ones increased in size and the wastes of our population became a serious problem as people congregated in industrial areas.

After World War II there was a somewhat sudden realization that the national water supply was being imperiled. An intensive drive was started to protect our streams, and thus the water supply of the nation, for without water nothing can live.

Although efforts were being made to correct pollution prior to World War I, and even greater effort was made between the wars, the greatest endeavor followed World War II. Between 1945 and 1952 about forty-five of the forty-eight states

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enacted pollution abatement laws, and the federal government enacted one. Other associated laws were passed. All these laws were based on various ideas of policy. To conserve space only the major policy considerations will be given place in this discussion.

1. Federal vs. state control of stream protection.
2. Stream protection to fit regional water uses.
3. Direct and indirect types of laws.
4. Laws for water protection to serve water conservation.
5. State compacts.
6. Federally controlled waterways.

Federal versus state control of water pollution as a policy matter goes back a good many years. The first laws that were even related to water pollution were the Federal Acts of 1889 and 1899. They were not really pollution laws, but were aimed at the prevention of shoaling in New York Harbor. However, comparatively early in the present century, as a result of a District Court decision in the northwest, a case of pollution by oil from a barge went against the barge owners and was upheld in the Appellate Court. No one has carried the appeal farther, and the law is still on the books.

A third law, the Oil Pollution Act of 1924, is also a federal law. As the name suggests, it applies to pollution by oil only in waters navigable "in fact." But again there was a change. The decision made in the case of the power permit on the New River in West Virginia changed the idea of navigable "in fact" to the idea that any stream which could be made navigable came under the 1924 Act. This really took the Act right back to the springhouse.

Up to this time the states had not been very active in control of pollution, although some had laws on the subject. However, the progressive enlargement of the problem was bringing it to the foreground. In Pennsylvania, the Shapiro Bill was introduced in 1932, but got nowhere. Then, in 1937, a more comprehensive bill was passed and signed into law. Other states were awakening to the fact that the Federal Government was too remote from their problems; also, that although thirty or forty bills were introduced into Congress, none got any consideration and consequently no protection was resulting. Thus, another policy idea was developing. This was based on the facts that the United States is a big country; it varies in topography, interests of the people, and in quantity of water available. So, a sort of "states rights" idea of control was introduced, and the feeling that the various states should control water pollution within their borders emerged. This bore fruit in the 1945–1952 era and the deluge of state laws followed.

This idea of local interests was an attractive one to the lawmakers. Flags could be waved over "what we have done for the home folks." There could be little question that the pollution problem was much more accute in the large city regions such as Chicago and Philadelphia. Large cities located on brackish or salt water had already found it necessary to go inland for water and these supplies were usually well back in headwater areas and could be protected easily.

However, in the regions where industrial activity was newly installed, and where sports fishing and similar recreational activity had existed for years, water pollution created the greatest disturbance. It was in these same regions that many of the state laws, which later were passed, had their beginning. Other water uses, such as grazing and irrigation, also became the reason for legislative action.

The state laws which were passed in the 1945–1952 period were of two general types and there have been many arguments about which type is the more effective. One type could be called the Pennsylvania type law. This is a direct type and states clearly what is required in the way of treatment for industrial wastes and sanitary sewage, sets forth associated requirements and establishes penalties. The other type might be called the indirect type and is encountered in states where population density and manufacturing activity is lower than in such highly industrialized states as Pennsylvania. In this type of law some division of state government such as the Fish and Game Commission, or a water pollution abatement commission, is charged with the job of abating pollution and is authorized to promulgate and administer rules and regulations for that purpose.

Both of the foregoing types of law reflect policy and are the result of the solution of policy problems. In the first type there is a "club," which in the final conclusion of those who wrote and backed the law was necessary. Industrial people had been able to defeat all attempts to provide for stream pollution abatement; consequently, it was concluded that they would have to be driven to do something, and the law was so designed. Actually, many industrial people were hurrying toward their own destruction because nothing can be done without reasonably clean water. Today, many of them would work hard to support the law they tried so hard to defeat.

The indirect type of law obviously is the result of policy decision to protect the sport and commercial fishing fraternity. However, in discussion with authorities in some of the states where this type of law is on the books, there is also some thought that this type of law reflects a better policy for solution of the whole problem. Actually, the direct type of law sets up a division of state government to administer the law, but it also carries the other features in the same act.

All sections of our country are not blessed with equal supply of water. The west and southwest in particular are so short of water that special laws which control use of water are on the books. In these locations the pollution abatement laws are aimed at protecting the available supply and result from a policy of strict protection of what water they have. Recently, one state on the eastern seaboard has recognized the swiftly narrowing gap between supply and demand and is considering laws similar to those in the west. This is the first instance of this kind that has occurred in the east where the idea has been prevalent that there is ample supply to meet all demands.

During the development of the large number of separate state laws, the problem of streams that form state boundaries or flow from one state into another came into the picture. In other words, what about interstate streams? This presented quite a problem because there had to be a reconciliation of the interests of the states involved.

Finally, on the basis of the fact that streams do not respect political subdivisions, the state compact came into existence. Such compacts had been created for other purposes and it was decided that similar arrangements would solve the problem for interstate streams.

State compacts vary in their degree of authority. For example, the so-called Ohio River Compact is endowed with a great deal of authority by Congressional approval. Other compacts such as those for the Delaware River and Potomac River are largely advisory and agreement on their suggestions is required of all the states involved.

For a long time, there has been the feeling that water pollution control should be handled by the Federal Government. This feeling continued, on the part of a number of interested people, after many states had enacted laws following the end of World War II and proposed federal laws were still being introduced in Congress. The only law to come out of all of this, however, was the one passed and signed in 1948. This law was passed as a sort of compromise, but it did meet the policy that the Federal Government should be in a position to step in where states made no effort toward cleanup of their streams, particularly in the case of interstate streams. Although the law started out to be a control on water pollution, in its final form it is a law which hangs over the head of the state as well as the source of pollution, but only becomes active after several years. This leaves the state in control as long as it exercises its authority, but it does not permit laxity to continue forever.

Other policy problems have presented themselves and still others will arise later, for necessary abatement of pollution has not been attained in all sections of the country. There are still regions where the primary controversy between industry and municipalities on one side and enforcement agencies on the other is flourishing. In general, however, these are rather localized and center around making any serious effort for stream cleanup. They will be cleared up, however, if for no other reason than that scarcity of clean water will demand that pollution abatement be carried out and that the presently degraded streams be brought back to usable condition.

Speaking of bringing a stream back to usable condition introduces the question of "How clean must a stream be?" This one question has brought about the use of thousands of words. It has to do with the conservation of what is probably our most important natural resource—water. Remember that one of the greatest problems in the whole effort of pollution abatement is the location of the "s" and the "v" in conservation; a great deal of the time these letters are reversed in their respective positions and there surely has been a lot of conversation in connection with water pollution abatement.

Most frequently the question "How clean should a stream be?" has been answered by saying it should be "reasonably" or "satisfactorily" clean. It then follows, "How clean is reasonably?" Obviously, this could be carried on to absurdity unless there is a technical approach to a solution. Here we encounter one of the major technical problems of the whole clean streams project.

There are two schools of thought in the matter, the chemical or sanitary engineering approach and the biological approach. No stream, or even a lake, stands still. They are dynamic in their being and there are dynamic cycles within them. Consequently, a sample collected from a moving body of water represents only the point sampled and, when analyzed, the results represent a point which may be miles away from the place of obtention, or may have been so mixed with other parts of the water in the stream as to be meaningless. It is claimed, however, that if enough of these samples are taken, a good idea of the condition of the water will be obtained.

On the other hand, the biological school of thought is that the sample should be a fixed one and the water in question allowed to flow over it. Their sample is the aquatic life in a stretch of the stream or a restricted area of a lake. The sample consists mainly of the bacteria, protozoa, diatoms, algae, rotifers, worms, insects, arthropods, and fish which are indigenous to the waters of the region. Some species of these various groups are intolerant of polluted conditions whereas others will tolerate quite serious pollution. The biologists examine the area and determine what species are present and in what quantity. These findings are analyzed, and from this analysis the condition of the flow is determined. The claim is made that this procedure will reveal what the condition of the water has been over some considerable period of time. A great deal of success has been experienced with this biological approach and an expanded use is anticipated because it gives results for the whole stream flow rather than just one point. In addition one stream survey will tell much about water condition for some time past rather than for just an instantaneous sampling.

Another rather serious technical problem in the treatment of aqueous wastes is concerned with dissolved solids. High dissolved solids in waste waters frequently require special policy consideration to permit disposal. The difficulty lies in the effect of osmotic pressure under the influence of which water travels from the life fluids of the various aquatic organisms to the surrounding stream flow. When the stream is high in dissolved solids, the organism will be dehydrated and therefore will die. It may sound ludicrous to say that a fish dried up and died while swimming around in water, but it can and does happen.

The serious phase of this problem as related to fresh water is that there is no way of reducing dissolved solids except by demineralization. Dilution will reduce the concentration, of course, but the amount of solids will be the same even though the concentration is lower. However, the stream flow is not equally increased, so the same amount of solids is introduced and the osmotic flow is set up just as if no attempt at dilution had been made. This problem is as yet unsolved unless transfer to an ocean is considered a solution—hence the establishing of special policy considerations in many instances.

The effect of phenol and phenolic substances on potable water supplies that are chlorinated has not been completely solved as yet because of the problem in phenol removal. The "medicinal" or "iodoform" taste and odor of some water supplies is well known to many. It results from the action of the chlorine to form chlorophenolic substances which contribute this taste and odor. Only a few parts per billion of phenol will produce the effect and the reduction of the phenol in some wastes to such a low concentration is not readily accomplished; it is also far from inexpensive.

This problem is further complicated by the lack of a good analytical procedure for determining concentrations of phenol of this magnitude without the use of very expensive and complex apparatus such as the mass spectrometer.

Phenol is a poison; but peculiarly, fish are the best removers of phenol from water. They will oxidize the phenol to a complete removal. The only trouble is that the concentration must be relatively small (of the order of about 10 parts per million) to start with and there must be a lot of fish.

The petroleum industry especially is confronted with a technical problem peculiar to some of its newer treatment methods for the removal of oil. Separators of the gravity type have been used for years by the petroleum industry to prevent the escape of oil carried by waste waters. However, separators of the gravity type will not break emulsions in which the oil is in the dispersed phase and water in the continuous phase. Such emulsions will carry oil into the public waters in quantities in excess of those which will create water pollution by oil. These emulsions can be broken by flocculation, and treatment methods of this kind are in use. They produce effluents very low in mechanically carried oil (down to under 10 parts per million).

In devising a procedure for determining low concentrations of oil in water the mass spectrometer was found to give high results because it showed the effects of dissolved hydrocarbons as well as those mechanically held. Different hydrocarbons are soluble in varying degrees in water and thus are retained. The problem, therefore, is to devise a test procedure which will record the physically suspended oil without showing the oil in solution. The dissolved oil may well exceed the suspended oil by several times and will present little problem because it will be destroyed by bacteria in the stream. This can be demonstrated in a trickling filter or an activated sludge treatment plant designed for the purpose.

What has been presented here does not include, by any means, all the various policy and technical problems in water pollution abatement. Many are highly localized or even specific to a particular industrial establishment. Two major problems, both nationwide, still remain. They are, first, to arouse interest in the cleaning up of our streams, or in other words, to make people realize that we no longer have an unlimited supply of usable fresh water in this country; and, secondly, to be continually on the alert for methods by which both municipal and industrial wastes can be so treated that those streams which have been destroyed can be brought back to usable condition and those which are fully usable will remain so.

Correction of a Fluviatile Delinquent: The Schuylkill River

Francis A. Pitkin

Interstate Commission on the Delaware River Basin

The task of correcting the delinquency of the Schuylkill River has consisted primarily of removing from the bed and banks of the river, for practically its entire length, the waste discharges of more than a hundred years of anthracite mining operations; and, in order to restore this once great waterway to a desirable degree of economic usefulness, the improvement of old and the construction of new municipal and industrial waste treatment works.

The Schuylkill River watershed drains an area of about 1,900 square miles in southeastern Pennsylvania. It has its source in the mountainous anthracite region in Schuylkill County and flows southerly 130 miles through rolling hills into the tidal section of the Delaware River at Philadelphia. Its fall averages about four and half feet per mile. Below Fairmount dam, which is within the city of Philadelphia, the river is tidal with a range of approximately 5.5 feet. Rainfall on the basin averages about 45 inches, of which 24 inches runs off the land and reaches the streams.

Floods of great magnitude are known to have occurred on the Schuylkill periodically for two centuries or more. Records of floods at Reading, about midway on the length of the river, go back to 1757. The highest crest elevation of record here occurred in September, 1850, when an elevation of 211.5 feet was reached. This elevation, it may be noted, is 12 feet above the "bank-full" flood stage of 199.5 feet. Floods only slightly lower occurred on three other occasions since that time. The greatest flood in recent years occurred in May, 1942, with a crest elevation of 209.4 feet.

The first record of contamination of the waters of the Schuylkill came in colonial days with the establishment of the paper and iron industries along the river and its larger tributaries above Philadelphia. However, the main source of pollution originated with the discovery of coal. One writer described it very interestingly when he wrote, "The beginning of the Schuylkill's downfall dates from a night in the year 1790 when, after a day's hunting, a roaming New England lumberjack named Necho Allen built his campfire among some rocks on Broad Mountain. He had built his campfire on a fine outcrop of anthracite and awoke to find the "stones" of his fireplace on fire!" Necho Allen's discovery of coal in the beautiful Schuylkill Valley became the "kiss of death" to thousands of acres of farm and woodland as well as hundreds of miles of river and streams. The discovery of coal added to the expansion of the iron industry in the valley, and inevitably transportation became a factor in the growing business of the region.

In 1815, the Pennsylvania legislature issued a charter of incorporation to the Schuylkill Navigation Company authorizing construction of a canal along the river. Thirty-two dams and seventy-two locks were constructed along the main stem of the Schuylkill between Port Carbon and Philadelphia, a distance of 108 miles. The canal system provided the means of transportation not only for coal and iron, but also for many other commodities.

New and better uses for coal increased the demand and, year after year, more tons of waste material from the increased mining operations were washed into the river and its tributary streams. At the height of the mining industry, it is estimated that more than two million tons of coal culm and silt were washed into the streams every year. Rains and flood waters carried the "black snake" of the coal regions downstream into the lower valley, despoiling the river and adjoining farmlands, choking the main channel, building up behind the navigation dams and filling the canal. The problem of maintaining the canal system became so costly in the face of competition from the railroads that a gradual abandonment started about 1910, and the last coal boat was locked through the lower section of the canal in 1917. Although small pleasure craft continued to be locked through the canal in the lower pools, this use also was abandoned in 1932.

One by one, the dams were washed out by flood waters, which carried the culm deposits downstream into the navigable section of the river and into the Delaware. In 1927, only a small amount of coal culm and silt had reached the tidal estuary. By 1944, 48 per cent of the material dredged in the tidal section of the Schuylkill was mine waste, and traces of culm were found in the Delaware River channel 10 miles above and 31 miles below the mouth of the Schuylkill River. In 1944, the mine waste dredged from the Schuylkill and Delaware River channels was 1,500,000 cubic yards, and further increases were expected. Another disquieting fact had been that for each ton of coal produced, approximately 20 tons of acid mine water were discharged to the streams.

Settlements along the river grew into towns and cities bringing other types of industry into the valley and causing the pollution problem to become progressively worse. The river became an open sewer, carrying the wastes of mining, industry, and municipalities. Over the years, conditions gradually became intolerable. Coal culm was rapidly decreasing waterway capacities and adding to flood hazard. The poor quality of water taken from the river made costly treatment necessary either for public supply or for processing in industrial operations. Recreational use of the river, once the pride and joy of thousands of people, had to be abandoned.

Early legislation, enacted by the General Assembly of the Commonwealth of Pennsylvania in 1905, was intended to prohibit the pollution of the waters of the state, but was applied only to municipalities. This brought about the construction of primary treatment plants by most municipalities between and including Reading and Conshohocken. Not until 1937 was the legislation amended to control the waste of industries, and a strong enforcement program was undertaken. Again in 1945 the legislation was amended to forbid the discharge of wastes, other than acid mine water, from coal mining operations.

For about fifty years, municipalities, industries, and civic organizations have worked toward correction of the conditions. The Federal Government was brought into the picture. On several occasions, the United States Corps of Engineers made reports on the river and recognized the culm problem. As late as 1938, the Engineers reported that the corrective action was not the responsibility of the Federal Government but of the Commonwealth of Pennsylvania and the mine operators.

In 1936, the Interstate Commission on the Delaware River Basin (Incodel) an agency of the states of New York, New Jersey, Pennsylvania, and Delaware was created and charged with the responsibility for planning the wise use of land and water resources of the Delaware River Basin. In 1943 Incodel reported on the pollution of the Schuylkill River by coal culm and silt. The Commission's plan for the restoration of the Schuylkill River called for a joint undertaking on the part of the coal operators, the Commonwealth of Pennsylvania and the Federal Government. It recommended that the coal operators spend approximately six million dollars to make installations that would keep additional coal culm from washing into the streams. It pointed out that, in view of the fact that the state had condoned the discharge of these wastes for a hundred and thirty years, it should assume the responsibility for restoring the river to its original bed and banks from Auburn to Norristown, a distance of approximately eighty-six miles, and that the Federal Government should restore the river from Norristown to the Delaware River.

The project was endorsed by the Schuylkill River Restoration Association and other interested groups. It was presented to the Attorney General, James H. Duff, who became an ardent advocate of the project. It was he who was instrumental in having the Governor, Edward Martin, adopt the program as a part of the program of his administration. Attorney General Duff had been untiring in his efforts to have the Sanitary Water Board work out methods of cooperation with the coal operators to prevent the discharge of coal culm into the stream. This resulted in the Board issuing orders to the coal operators in 1944 to discontinue any further excessive discharge of solids into the headwater streams and led to the amendment of the Pure Streams Act in 1945 which outlawed the discharge of silt into the streams. Pressure was brought to bear in industries and municipalities to attain conformance with the law through construction of pollution abatement works.

In accordance with Incodel's plan the United States Corps of Engineers was asked by Congress to review the project. In the light of federal responsibility in flood control and navigation, the Corps concluded that the Federal Government was justified in the expenditure of ten million on this project, since it would be more economical to remove the silt in the lower Schuylkill than to wait until it washed down into the navigation channel, where its removal would be a federal responsibility. All hurdles were now cleared for the execution of the work.

The Schuylkill River desilting project was authorized by act of Pennsylvania's General Assembly in June, 1945, during the latter portion of Governor Martin's administration. At that time five million dollars was appropriated to the Water and Power Resources Board of the Department of Forests and Waters as the administrative agency to initiate the project. Subsequent appropriations were made by the 1947 and 1949 legislatures in the amount of twenty-one million dollars, and further funds of eight million dollars were provided by Pennsylvania's General State Authority—a total of approximately 35 million dollars of state funds.

The first year and a half after the authorization of the project was spent in setting up a legal and engineering organization to function for the state and in acquiring the property of the Schuylkill Navigation Company and other lands and rights-of-way.

In January, 1947, James H. Duff, Attorney General, became Governor of the Commonwealth of Pennsylvania. He appointed Rear Admiral Milo F. Draemel (retired) as Secretary of Forests and Waters to execute the river restoration project.

In June, 1947, the Water and Power Resources Board entered into an engineering management contract with a group of four engineering firms functioning as the Schuylkill River Project Engineers. The contract required the Project Engineers to do the planning, to prepare contract plans and specifications, and to provide the supervision and management of construction and execution. The Project Engineers received all directives from the Secretary of Forests and Waters.

The plan for the restoration of the Schuylkill River developed by the Schuylkill River Project Engineers was based upon five principles:

1. The stopping of the discharge into the river of the wastes resulting from coal mining operations.

2. The use of the natural transporting power of the river to carry the accumulations of culm in its channel from its upper regions, in which there are high velocities, to points lower down the river from which the culm could be removed.

3. Provision for desilting or settling basins in the river to accumulate the culm carried into them by the river.

4. Provision for the removal of the culm deposits in the channel of the river and along its banks, and from the settling basins, and with storage facilities or suitable impounding basins along its shores.

5. The reshaping of the river channel to improve its ability to pass flood waters.

The restoration of the Schuylkill presented a real challenge to the engineering profession. Since no like project had ever been attempted there were no rules to follow to accomplish the job.

It was recognized that, even after the stoppage of the discharge of new mining wastes to the river, there would, for a number of years, continue to be large quantities of culm carried away during flood periods from the undredged channels of minor upper tributaries and by erosion from the many culm banks adjacent to its course.

The Pennsylvania Sanitary Water Board, through its Industrial Waste Division, has been successful in requiring all active mining operations to stop the discharge of coal wastes to the river. This has been accomplished by the coal companies through the construction of slush and silt impounding basins in which the solids settle. The effluent from these basins returns to the river.

To use effectively the natural transporting power of the water and to prepare properly for the trapping of the coal culm, certain changes in the river channel were necessary. Five old breached navigation dams were removed because they constituted obstacles in the way of free flow. Within a year after their removal, the scouring action of the river was observable by the manner in which the river cleared the culm from its bed and carried it downstream.

Four old dams were used as impounding basins. Three new permanent basins were constructed. Two of these permanent desilting basins were installed along the river by the construction of monolithic concrete dams at Kernsville and Auburn. The Auburn pool is 1.75 miles long, and the Kernsville pool 1.25 miles. The third new desilting basin was formed at Tamaqua by excavation made below the natural river bed with a low stone weir in the original river bed. This type of development was necessary because the terrain was such that the river level could not be raised without excessive expense for highway and railroad relocation.

The Commonwealth provided specially built dredging equipment for removing the culm deposits from the river channel and from the desilting basins. Four 15-inch electric-cutter pipeline dredges and one 8-inch diesel-cutter pipeline dredge were built under contract. Each of these dredges is portable and is so designed that hulls and equipment can be disassembled, the hull separating into nine sections to permit easy transport by land from one pool to another. The four electrically operated dredges were supplied with energy from local public utility service lines. Each dredge had its own shore substation, shore cable line and shore-to-dredge cable.

Silt-impounding basins were required to receive the dredged material on shore throughout the course of the river from Kernsville to Norristown. These spoil areas were formed by constructing earthen embankments made of local materials at sites selected because they were suitable to the purpose and were within reasonable distance from the dredging stations. Impounding basins have also been provided at each desilting basin for the storage of dredged materials produced by periodic maintenance dredging.

The reach of the river from Kernsville to Norristown was divided into five sections, not of equal length, each section being determined by its volume of culm, the availability of impounding basins, and the distance between the dredge locations and the nearest impounding basin.

All the dredging was done by so-called cutter hydraulic pipeline dredges. This type of dredge is composed of a heavy-duty centrifugal pump mounted within the hull of the dredge from which a suction pipe provided with a revolving cutter-head at its end is carried down a ladder boom. By means of hoists, the ladder can be raised from, or lowered to the bed of the river, and the hull can be swung from port to starboard. Materials in the river cut away by the cutter head are sucked up the ladder pipe by the pump and discharged through a pontoon pipeline and shore pipeline to the nearest impounding basin. The distance that material can be moved in this manner is about 5,000 feet. For pumping to greater distance "booster" pumping units were provided in the discharge pipeline. This enabled the delivery of material in one section of the river up to a distance of 20,000 feet. Power for operating the electric dredges was taken from substations via a shore cable in which connections were provided every 500 feet for the shore-to-dredge feeder cable.

Materials carried by the water pumped to a silt impounding basin were settled out of the water by gravity, and the clarified effluent water was returned to the river through an adjustable weir. Solid materials carried in the water handled by the dredges averaged approximately 15 per cent.

Between Reading and Norristown, the depth of water in the reaches between the old navigation dams was too shallow to provide flotation and maneuverability for the dredges. Thus, it was necessary to provide temporary dams in three sections of the river in order to raise the water level during dredging operations. To expedite the project, contractor-owned dredging equipment was employed in three sections of the river.

The channel rectification involved the clearance of culm from the river bed and its banks. Culm within the flood plain, inaccessible to the dredge, was bull-dozed or dragged into the river from which it was then dredged. The task included the removal of old bridge piers, of fallen timber, and also of brush and stumps from a strip 40 feet in width along both banks of the river. All this work was necessary to improve the channel and reduce the crest elevation of flood waters. Details of the work are contained in the "Final Report of Schuylkill River Project Engineers on the Schuylkill River, Pa., 1947-1951."

The project was commenced in June, 1947, and was completed in June, 1951. Under Admiral Draemel's able direction, approximately 90 miles of river were restored to its original channel. More than twenty million tons of coal culm and silt were removed from the river and stored for future reclamation. Several operators are at work recovering coal from the mixed material in the storage basins. The material contains 30 to 40 per cent recoverable coal, for which the state is receiving about thirty cents per ton. At present, four to five thousand tons of fine-size coal per month are being recovered. Recovery is gradually increasing as new markets become available.

The United States Corps of Engineers in its report on the Schuylkill dated December, 1945, recommended that the restoration of the Schuylkill in its lower reaches from Norristown to the Delaware River be accepted as the responsibility of the Federal Government. Congress accepted these recommendations, and has appropriated sufficient funds to carry on the project. Almost immediately upon the Commonwealth's completion of the restoration project above Norristown, the Corps of Engineers initiated its dredging work below Norristown. Work has been completed in the Plymouth and Flat Rock pools, from which about 900,000 cubic yards were removed, and operations have been started in the final section, the Fairmount pool, in the city of Philadelphia. It is estimated that approximately 4,000,000 cubic yards will be removed from this final stretch of the river.

The success of the operation is shown in figures compiled by the State Sanitary Water Board, which is the agency responsible for the control of mine waste discharges into the waters of the state. At the present time, it is estimated that not more than 50 tons of solids per day are discharged into the river from the forty-four presently active coal preparation plants. These figures relating to the tonnage of solids discharged do not include the erosion from refuse and silt banks which have been accumulating since the early days of anthracite mining, and which have been and are being constantly worked over to reclaim smaller sizes of coal as the newer recovery processes are developed.

Investigations of surface water resources in Pennsylvania have been carried on for many years under cooperative arrangements between the Pennsylvania Department of Forests and Waters and the United States Geological Survey. To handle the special work of the Schuylkill Project, a laboratory and field office was established at Schuylkill Haven. During the early stages of the Schuylkill River Restoration Project, the investigations were aimed at meeting the requirements for data for planning and appraisal of the Project. The object of the investigation was primarily to have an account of the benefits of the cleanup program on the river; to have a record of the results obtained from desilting operations at the mines and of the amount of erosion from culm banks as a basis of design for desilting basins; then to obtain a record of their effectiveness after completion; to obtain data on acid waters in the basin and changes in quality that may result from the desilting project.

Twelve daily sampling stations were established at selected locations along the river between the coal fields and the Fairmount pool for the purpose of determining the nature and quality of suspended solids and dissolved material transported in different sections of the river. A systematic sampling schedule was followed at each station, samples being collected for measuring the suspended sediment concentration, particle sizes of sediment, chemical characteristics of the water, and other related properties as required. Similar data were obtained from time to time at other places in the basin for such purposes as correlation of the records for the principal sampling stations with the effects of man-made and natural features of the river basin.

With the completion of the Schuylkill Project above Norristown, all but two of the sampling stations were discontinued. The remaining stations are located at Berne, in the upper section of the river, and the other at Manayunk, at the upper limits of the Fairmount pool.

To summarize quickly the results of the studies can not give a fair indication of the effective planning and painstaking execution of the work done. However, a summary which shows the ratio of the tons of silt carried per second-foot day of flow at Berne station is indicative of the results obtained by the mine operators in stopping discharges of culm and silt and provides information as to the amount of silt which is being washed into the river from culm banks by high river flows. The summary of data obtained from October, 1947, to June, 1949, the period before the silt abatement program was in full effect, indicates a ratio of silt to second-foot days flow as high as 9.5 and as low as 1.2, with an average ratio of 3.06. During the latter part of 1949, when the program became effective, up to March, 1953, the highest ratio was 1.69, and the low ratio was .01, with an average ratio of .234. The high ratio of

1.69 was due to high water of November 25-26, 1950, with a peak discharge of 23,400 second-feet which carried 70,100 tons of the monthly total. The figures clearly indicate that the daily flow of the river carries little silt from coal operations, whereas the higher flows due to heavy rainfall carry considerable silt eroded from stream channels, banks, and old culm deposits.

Culm bank erosion and erosion from the channels and banks of the streams provide the bulk of the material now moving into the pools provided to intercept the silt moving downstream. Maintenance dredging in these permanent pools prevents the silt from moving on downstream. Since the completion of the project in August, 1951, it has been necessary to dredge the four basins in the upper section of the river above Reading. There have been removed from these pools 2,066,000 cubic yards of eroded material which has been stored in adjacent impounding basins. The Tamaqua pool, located on the Little Schuylkill and the smallest of the desilting pools has been dredged for the second time. It is significant that no maintenance dredging has been found necessary in any of the three desilting pools below Reading. This maintenance dredging was anticipated and is expected to be required for a number of years. Stabilization of the stream and culm banks by vegetation will result in decreasing the amounts of eroded silt moving downstream and will gradually reduce this maintenance operation.

Substantial improvement in the river is evident and is acknowledged by everyone, even those who opposed the project at its inception. The river water, once black and murky, now runs clear and sparkling. Flood levels have been reduced with substantial saving in flood damage throughout the entire length of the river. Municipalities and industries report a much better quality of river water, with resultant savings in treatment costs and a better finished product. New industries in need of adequate supplies of good water are locating along the river, and others are considering sites on which to construct plants.

Sediment-Flow Data, Schuylkill River at Berne, Pa.

Month	Q_w, Second-foot days^a	Q_s Tons^b	Ratio^c Q_s/Q_w	Remarks
1947				
October	6,058	32,110	5.3	
November	37,008	352,700	9.5	*November* Pollution abatement program begins. First action taken by some coal collieries to prevent culm from entering streams.
December	14,667	36,230	2.5	
1948				
January	13,053	35,900	2.8	
February	23,001	153,700	6.7	
March	39,934	163,900	4.1	
April	41,585	140,300	3.4	
May	46,949	155,700	3.3	
June	14,878	30,030	2.0	
July	9,034	18,100	2.0	
August	7,823	18,300	2.3	
September	4,873	5,690	1.4	
October	4,839	6,960	1.4	
November	15,230	72,980	4.8	
December	28,368	144,100	5.1	

1949				
January	48,633	109,200	2.2	
February	28,463	22,720	.80	
March	17,603	6,930	.39	
April	33,025	29,460	.89	
May	20,681	10,700	.52	
June	8,256	1,750	.21	*June* Pollution abatement program in full effect. All coal colliery wastes effectively stopped from entering streams.
July	5,858	2,220	.38	
August	4,452	684	.15	
September	5,090	479	.09	*September* 12 Kernsville desilting basin placed in operation.
October	5,302	85.7	.02	
November	6,734	238	.04	
December	16,536	8,390	.51	
1950				
January	23,743	2,650	.11	*January* 6 South Tamaqua desilting basin placed in operation.
February	37,135	12,140	.33	
March	43,844	19,380	.44	
April	25,708	1,250	.05	*November* Auburn desilting basin placed in operation. Flood of Nov. 25-26 (Peak discharge 23,400 sec. ft.) carried 70,100 tons of monthly total.
May	23,538	377	.02	
June	19,330	308	.02	
July	18,073	2,560	.14	
August	8,036	186	.02	
September	8,272	476	.06	*December* Flood of Dec. 4-5, 8 (Peak discharge, 23,400 sec. ft.) carried 56,200 tons of the monthly total.
October	9,889	2,406	.24	
November	44,282	74,791	1.69	
December	68,930	61,323	.89	

SEDIMENT-FLOW DATA, SCHUYLKILL RIVER AT BERNE, PA. (*Continued*)

Month	Q_w, Second-foot days[a]	Q_s Tons[b]	Ratio[c] Q_s/Q_w	Remarks
1951				
January	38,604	7,426	.19	
February	46,060	18,685	.41	
March	35,688	2,870	.08	
April	36,285	3,349	.09	
May	14,477	2,913	.20	
June	11,684	896	.08	
July	14,795	5,906	.40	
August	14,929	707	.05	
September	7,972	73	.01	
October	9,253	93	.01	
November	45,824	10,012	.22	
December	47,405	14,966	.32	
1952				
January	49,493	3,041	.06	
February	27,079	1,519	.06	
March	53,040	43,672	.82	
April	62,002	9,348	.15	
May	51,459	2,465	.05	

1952 (*Continued*)				
June	17,668	206	.01	
July	20,260	1,984	.10	
August	18,586	140	.01	
September	30,724	7,653	.25	
October[d]	7,015	366	.05	
November[d]	42,647	55,927	1.31	*November* High water of Nov. 22 (Peak discharge 19,870 cfs) carried 49,500 tons of the monthly total.
December[d]	52,301	8,307	.16	
1953				
January[d]	48,195	7,885	.16	
February[d]	32,238	1,370	.04	
March[d]	43,205	2,423	.06	

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[a] Total of daily mean discharges in second-feet.
[b] Tons of suspended sediment.
[c] Tons of suspended sediment per second-foot day.
[d] Unpublished record subject to revision.

It is surprising how quickly the public recognized and accepted the opportunity to use the renewed recreational values of the river. Boating has revived in all the pools. The Felix pool, above Reading, was in 1953 the site of a regatta in which more than a hundred outboard motorboats participated and in which sculling races were the featured event. Summer cabins along the river, many of them long abandoned, have been renovated and put back in service. Many new homes are being built in the river valley, and property values have increased.

The water in the river above Maiden Creek is acid owing to the large quantity of mine water discharged to the streams, and therefore does not support fish life. When mixed with the highly alkaline water of Maiden Creek, it becomes alkaline and favorable to fish life. The State Fish Commission has restocked this section of the river, and, for the first time in many years, fishing has become a popular pastime for Izaak Waltons.

The restoration of the Schuylkill River has been an outstanding accomplishment. No one will debate the point that it has cost a large amount of money. But, as a proud father recently said, "It was worth every cent of the cost just to see the look on my eleven-year-old boy's face when he walked into the house with a four-pound bass."

Water in the Future

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Studies of total water resources of the United States indicate that the nation now has an abundance of water for industry and that it will continue to have, even if the industrial use of water increases, as predicted, from the present level of 80 billion gallons a day to more than double that amount in 1975. In view of that conclusion, how can one explain the many areas of water shortage widely scattered over the country? What light do trends in industrial location throw on the relative abundance of industrial water for the next few decades? What can be done to keep areas of shortage from expanding and even to eliminate them? What major changes in water needs and supplies appear on the distant horizon? These are the questions to which this paper directs attention.

National, Regional, and Local Resources and Needs

The first step commonly taken in judging the abundance of water for the near and distant future is to compare resources and uses on a national basis, to see what margin exists to care for growing needs and new uses of water. Such an analysis is, on the surface, a comforting one. It shows that the total withdrawal of fresh water for all purposes, such as municipal water supply, private industrial water, and irrigation, is equal to only one-eighth of the total yield of streams and aquifers. Moreover, a large part of the water withdrawn is returned to streams or to the ground, where it is available for withdrawal again and again. Besides, there are the oceans to draw upon. Such considerations have led to the comforting assertion by informed persons that there is a good margin above foreseeable future needs. And so there appears to be, provided, among other things, that adjustments are made to variations in water resources in place and time. References to national totals are positively misleading if one stops short of considering the geographic location of resources and of needs.

Water is notably local and regional in occurrence. Even a crude analysis of geographic variations suffices to support this point, as one contrasts the arid West and the humid East; and, within the West, recognizes the humid Pacific Northwest, the winter-rain-summer-drought of the California coastal areas, the rainy mountains in the dry interior, and the startling contrasts between the windward and leeward sides of mountain ranges. To these contrasts in rainfall one must add geographic variations in surface drainage, in lakes and wet lands, and in ground water, the last varying not only with climate and surface configuration, but also with detailed differences in bed rock and mantle rock. Only by a close local and regional adjustment of industry to water can limitations imposed by geographic location be avoided and shortages minimized. All who give even casual attention to waters know, moreover, that the average flow of streams is purely a mathematical fiction, unless perchance sufficient storage has been provided by man or, in very exceptional cases, by nature. The steady day-by-day requirements for industrial and municipal water may quickly equal and even exceed the minimum flow of streams or the rate at which ground water can be withdrawn. It is not long until the people in a given area are actually depending not on a "natural" resource, but on one improved by reservoir storage, on a resource raised by human effort well above its natural level of usefulness.

Thus the conclusion that the United States has plenty of water for the foreseeable future must be qualified by recognizing that this abundance is sharply localized and that, with the exception of certain ground water resources, it is fluctuating day by day, month by month, season by season, and even year by year. Limits to available water can quickly appear unless needs are adjusted to geographic variations in the resource and unless that resource undergoes marked beneficiation.

Present and Future Location of Demand for Industrial Water

Are users free to adjust to geographic variations in water supply, and can they succeed in regulating the flow and improving the quality of the available water? The demands of industry are spot demands—the factory wants water where the factory is to be located. What bearing does the present location of industry have on water for the future, and what are the trends in the location of new industries? Where are future industrial users of water likely to be located?

The bulk of industry in the United States is found in a compact manufacturing belt. Since Sten de Geer's classic study of the American Manufacturing Belt in the early 1920's, geographers have been analyzing it in its various aspects. Instead of looking to the future for emerging geographic patterns of industry, as suggested in the Paley report, I believe that the general patterns for industry have already emerged, so far as the next generation is concerned, although notable modifications are in view.

The geographic location of the American Manufacturing Belt is relatively stable. A study some twenty years ago of its northern and southern margins impressed me with the extreme slowness with which expansion of the Belt had taken place. It did not come as a surprise, therefore, for studies of industrial change between 1939 and 1947 to emphasize the stability of the Belt. Although the number of industrial workers increased 52 per cent for the country as a whole, most of that growth was in previously established industrial regions. "The general pattern of plant distribution by regions," states one investigator, "did not change significantly," during this period. "Industry," he writes, "continued to be concentrated in the industrial North," that is, in the American Manufacturing Belt. Several investigators have recognized, however, that growth was most rapid in the southern and western portions of this Belt.

As is well known, the Belt is rich in water resources, and very fortunate indeed in that regard; and yet to say that it is fortunate that the American Manufacturing Belt is humid is a little like the remark of a devout but unperceptive man that it was providential that so many cities were located on rivers. The connections between cities (the loci of most industry) and waters are many. The most evident, and at the same time the most fundamental, is that American cities have grown by serving their trade areas, and the most productive trade areas are the humid ones. What are the prospects for water in the near future in this main Belt and in the East and West in general?

According to the Paley report, probably none of the ten largest water-using states in the country, with the possible exception of Texas, could double withdrawals of good water without heavy cost. On the other hand, probably half of the states could double withdrawals at relatively little cost, and a few states could increase withdrawals ten to twenty times. The report adds, "Probably two-thirds of the potential water supply that can be cheaply developed is in the area south of the Ohio and Potomac River basins and east of southeastern Kansas and eastern Texas." It is precisely into the margin of this area that the Manufacturing Belt has been expanding!

The Columbia River area is the one part of the West with significant margins above current needs. With the water in the West as a whole considered as developed to 80 per cent and the favored position of irrigation as water user in the West, it is clear that water may act as a limit to industrial expansion in that vast area, unless exceptional economies are practiced. In the East it is reasonable to suppose that water scarcity will not have much effect on regional location in the near future. However, in view of shortages already developing, water will be increasingly important as a localizing element within the Belt.

There is no doubt that water supply problems will grow with the years, even in the most favored areas in the East. New uses are appearing, and the quantity needed is growing rapidly. Moreover, this demand is spot demand, and water resources of any locality, even with extensive storage, have an upper limit. It is a well-known principle, too, that city and industrial growth induce further growth and that industries cluster where similar industries have proved successful. Thus one concludes that water shortages are reasonably certain to occur during the next two decades in all industrial areas unless pains are taken to develop "water sources that are of sufficient size and dependability to permit continuing growth, and to provide the necessary expansion" of facilities.

Nor is that quite all: it is assumed that the water supply is reliable, even though fixed in amount. Here one should keep in mind that American industry depends essentially on a beneficiated supply, that is, on the flow of streams as regulated by reservoir storage. But dam sites are scarce, and rivers are silt-laden. Depreciation of storage capacity will become increasingly serious as the years pass. For these and other reasons, an abundance of water for the near future will be assured only by taking thought "well ahead of the need" and by paying more for water. The uphill climb of the cost curve has begun for water, as it has already for timber and many other natural resources.

So much for general needs for industrial water. What of particular industries? Here is one of the more optimistic aspects of the problem. It is of critical importance that 5 to 6 per cent of the industrial plants use about 80 per cent of the total industrial intake. Of the major users, steam electric plants use 44 per cent, the steel industry 16 per cent, petroleum refining 9 per cent, and wood and pulp 5 per cent. Probably three-fourths of industrial water is used for cooling. The use of water for condenser cooling in steam plants involves spot and regional location of power plants to serve established markets. It is reasonable to suppose that this need will continue to center in cities and regional manufacturing areas, and both are notably concentrated, as we have seen, in the American Manufacturing Belt. The steel industry, on the other hand, is undergoing shifts to accommodate changes in sources of ore. There is a definite opinion that ocean ports will be more favorable than interior locations for new plants, together with the Great Lakes shores when the St. Lawrence Seaway is completed. Much of the petroleum refining is already centered in the American Manufacturing Belt and outlying manufacturing areas; but it too will be more and more a coastal activity as America draws on additional foreign supplies. Pulp mills seek forest areas, and these are generally areas with an abundance of water and with relatively little industry. The parts of the United States in which pulp and paper manufacture has been expanding are the Southeast and the Pacific Northwest, where a wide margin of water above needs exists.

What about the water uses that make severe demands on quality? The growth of chemical industries is increasing the demand for water low in organic matter, minerals, acids, and gases. To the extent to which these industries are free to ignore market and raw materials and labor, they will undoubtedly seek out the best water—they will hunt headwater streams and favorable ground water supplies; on the other hand, they can treat and are treating their water supplies to secure the quality needed.

What are the conclusions to be drawn from this consideration of intensity and trends in the geographic location of industry?

1. A relatively wide margin of water above needs occurs mainly in the East, but even there the water is sharply localized, markedly fluctuating, and badly polluted. Scarcities are sure to spread if these conditions are ignored.

2. Industry is even more sharply localized than is water and is likely to remain so. One may expect the principal demand

to continue in and near the American Manufacturing Belt. Heavy water users will seek out rich aquifers and large rivers and lake and ocean shores to a degree not practiced hitherto.

3. Additional water supplies will be secured at increasing cost. Over wide areas the readily available low-cost water supplies have been developed.

4. Moreover, the certainty of water shortages is inherent in the expanding economy of localities as water needs outrun the limits of local resources and as use impairs quality.

In sum, more effective adjustment to variations in water resources and more efficient use of water are needed to guarantee adequate water supplies for the near future. The water supply in the principal industrial areas is not running out, but the day of cheap water, not needing beneficiation in quality or regularity of flow, is nearly over.

Water for the Near Future

The general conclusion from the above analysis is that, in spite of the rich endowment of the United States in water, particularly the eastern states and the Pacific Northwest, shortages will spread, limits will cramp industry, and over-developments will become more numerous. These conditions will obtain until the face of the United States is pock-marked with chronic water problems, unless they are attacked locally, by river and artesian basins, and, in some ways, by the nation as a whole.

The principal measures required to insure adequate water supplies for industry and competing uses during the next few decades include the following: (1) Location of new industry where water surpluses are known to exist; (2) Expansion of detailed information regarding water resources; (3) Local and district organization of water supply systems; (4) Resolution of competing uses for water; (5) Protection and improvement of water; and (6) More effective use of available water.

Although the distribution of most industrial need will doubtless remain pretty much where it is, the *location of new* *plants* will reflect more and more closely the occurrence of available water supplies within the general area in which the basic conditions, such as market, labor, raw materials, or power, are favorable. Certain to appear increasingly attractive are the relatively undeveloped waters of the Southeast, especially of the Atlantic-Gulf Coastal Plain, rated as the most productive ground water area in the nation. Large rivers will exert even greater attraction as more use is made of the valley aquifers, that is, the river bottom gravels hydraulically connected with streams. The Great Lakes will exercise still another pull on industry. Adjustments will have to be made in detail to water resources, adjustments which will be facilitated by every advance in the knowledge of the geographic distribution and time variations in water supply.

One can hardly stress too much the need for *additional knowledge of water resources.* True, much information of a general sort is available, but industrial demand is spot demand; just what water is available at a particular place is the issue. As the Engineers Joint Council put it, "This survey [of water resources] should be both local and areawise with respect to major river basins and geological formations." As the demand for high-quality water increases, more attention will be directed to ground waters, a field about which there is probably the least areally spread knowledge of any major resource. The study of water resources is an urgent need: long-time records of rainfall and of surface flow and ground water are essential to close use of the water. Fifty years hence adequate records will be available only for the areas for which observations are now being recorded.

Water shortages often occur because of lack of adequate foresight and of *organization,* of *planning,* and of *execution of plans* well in advance of needs. The simple fact is that industrial needs nearly always exceed water resources at or near the factory site. The problem is, therefore, one of areal expansion of sources, and that involves organization, pooling of financial means, and the harmonizing of the claims of many persons for the same water. On a local basis, the water district is the organizational device that seems best suited to the need. Proper legal measures and timely organization and execution of plans are required to keep supplies ahead of expanding needs. At least ten to fifteen years are required between the adoption of a plan and its realization in the development of water resources for a community.

In parts of the East, and in much of the West, adequate water for industry in the near future depends on the *resolution of competing uses* of water. Interest centers primarily on such uses as water for cities and for irrigation and as a carrier of wastes. As the principal competitor for water in most industrial areas is municipal, an efficient use of city water goes hand in hand with guaranteeing sufficient water for industry. All major steps in insuring city water are helps, such as metering, storage, and local and regional agreements to provide and share in river basin and ground water resources. In the East no major conflict with irrigation is likely in the next few decades; on the other hand, most of the economically available water in the western states is allocated to irrigation and is not available for large industrial requirements without costly acquisition of farm rights and properties. Moreover, irrigation has already overreached itself in many parts of the West. The West will have to decide whether its future is to be cramped by the priority system which puts irrigation above industry.

In meeting the needs for industrial water in the next few decades, much effort must be exerted in the *protection and improvement of water.* Most important is pollution abatement. To conserve the quality of water is the principal problem in the East. Too long has the support for pollution abatement come mainly from wildlife enthusiasts. The Engineers Joint Council concludes that pollution of streams from which water supplies are to be taken "must be controlled within limits compatible with its purification for domestic use." Water will not be as free to use for unregulated disposal of waste in the near future as in the past.

The need for pollution abatement extends to ground water.

Here is an area of scanty knowledge, of misuse, and of unregulated management that will change in the next few decades as the employment of wells for pollution disposal is limited, as control measures check intrusion of salt water along shores, as withdrawals are regulated to equate withdrawal with recharge, and as greater use is made of the ground for the storage of water.

As Americans crowd against low-water limits of streams, increasing use of storage will be required, not only to offset seasons of low rainfall but also to counteract years of below-normal precipitation, particularly in the Middle West. Already storage reservoirs provide nearly half of the water used by the nation's industries. Thus measures to meliorate both low- and high-water flows and to reduce sedimentation are essential, not only for water supply but also as means of flood control. The prospects that the American people will move rapidly ahead in the support of land-use measures to prolong the life of storage reservoirs are clouded in the haze of political controversy. In any event, I feel sure that such improvements as might occur will be of relatively little importance in the next two decades. The showdown on stream regulation, certain to come, is not in sight in this generation.

Among the various measures for water conservation, none promises more immediate relief in areas of existing shortage nor appears more essential as the years pass than does the *more effective use* of available supplies. This involves, for one thing, more extensive use of salt water for cooling. "Many water shortages, now existing in the seaboard areas and in locations where underground salt water is available, could be minimized or completely corrected merely by the use of the available salt water," declared the Engineers Joint Council. Of major importance is the reuse of waste waters, such as that made by the Sparrows Point steel plant of Baltimore sewage. In a sense this is a part of a larger measure, that of repetitive use of water. This is "essential for the long pull." The opportunities are great: for example, in 1950 more than half of the 3,000 industrial plants surveyed did not recirculate water, whereas canners in the Pacific Northwest have found that they can cut water use about one-half, and a western steel mill has cut water requirements per ton of steel from 65,000 gallons to 1,400 gallons of fresh water. In the prevailingly lavish use of water is a wide margin that can go far to meet the genuine needs of industry in the near future.

The employment of these various conservational measures would guarantee adequate water supplies for industry in the principal industrial areas of the country in the next few decades. Failure to employ them will unquestionably result in a rapid increase in the number and gravity of water supply problems.

Water for the Distant Future

The view for the next twenty to twenty-five years seems reasonably clear, what with knowledge of the past and present water situations and the certainty that major innovations will take years to have a widespread effect. The more distant view, as always, is considerably less certain. We may be sure that various conditions will exist that we have no way now of anticipating. But a number of identifiable figures do loom on the horizon. Doubtless each of you has looked eastward at dawn at a distant ridge on which the various objects stand out sharply against the brightening sky. Some of the figures could be described at once, but others only vaguely. The total effect may have had little relation to the relative importance on the ground of the various objects. Something like this is sure to be the view one gets of what lies in the distance in the field of water for industry.

In the distant future lies still greater demand for water, both for industry and for competing uses. It is estimated that the 1975 withdrawal for industry will be two and one-half times that of 1950, an amount considered about equal to the estimated maximum supply available for development under present conditions. Moreover, I doubt if this estimate of needs includes that of some of the water-hungry industries that appear on the horizon, such as the development of atomic energy and the making of liquid fuels from coal. This country has moved into the period of liquid fuels, and the prospects are that we will soon depend on coal as their main source. But hydrogenation of coal is a heavy user of water, 6,000,000 gallons per 10,000 barrels of oil. Moreover, there is reason to believe that this industry will be, in terms of market and coal resources, mainly in the East and probably largely in the American Manufacturing Belt, where it will compete with other water-hungry industries. If costs for atomic power are reduced and the mineral base expanded, it, too, may create a sizable water problem, although one cannot feel as confident regarding the geographic location of the demand for water and the consequences of waste disposal. The need for high-quality water will be vastly greater, too, for this country has not seen the heights to which the chemical industries will surely go.

Among the competing demands for water, demands not now noteworthy but looming much larger on the horizon, is water for irrigation in the humid East. If the nation should decide that national subsidy of land improvement must be justified by national needs, if the money is to be invested where it will do the most good, if experiments should prove that irrigation of humid land is more efficient than that of the remaining irrigable dry land, and if enough individuals decide that supplemental irrigation of their crops will pay off, competition between irrigation and industry would become one of the major problems in some eastern industrial areas.

To offset these increasing needs, what new sources of water may be available in the distant future? Certainly the preparation of sweet water from salt will be more important than now, although its significance will apparently be limited to coastal areas and to arid and semi-arid lands. Since irrigation water produces only 10 cents worth of agricultural produce per 1,000 gallons of water used, it is doubtful if water from the sea, costing about 30 cents per 1,000 gallons at a cheap-power location, will be used extensively for that purpose unless and until some unconventional power source brings down costs. It is quite unlikely, moreover, that sea water will be purified and pumped long distances inland to factories in humid areas where used water is available. Purified salt or brackish water will be a major factor in coastal industry; there is little likelihood that it will be as significant in inland industry except perhaps in the West, although a concentrated attack on the demineralization problem may prove economically advisable for inland industries faced with ever more difficult problems of disposal of byproduct salt water. Where water for cooling is the essential need, it is possible that new techniques or a wholly new principle of cooling that would recover heat for useful purposes may significantly reduce this requirement, a possibility enhanced by the fact that requirements already equal or at times exceed the available supply in some areas.

As for rain-making, who can tell? To date the chief concern has been in arid and semi-arid areas. Should this continue to be true, there would be little bearing on industry for many years, unless rain-making in the West is found to reduce rainfall in the East. I confess that this figure does not form a clear silhouette on the horizon. As "large-scale realization" in redistribution of rainfall is "not possible with our existing knowledge of meteorology," this remains an item for which we cannot even imagine the essential elements in our projection.

Instead of looming large on my mental horizon, these figures—sweet water from salty water and rain-making—are diminutive so far as the American Manufacturing Belt and its chief outliers are concerned. Rather there are other less novel but more important figures. One may expect, for one thing, more accurate local and regional evaluations of water resources: without them there is no real hope of a close fit of water needs to resources. On the horizon is a far greater body of knowledge of ground water and of practice in its development. As water needs mount, ground water will be drawn on more and more for water, with the useful properties of low, uniform temperature and freedom from suspended matter.

In addition, as surface storage is reduced by sedimentation, ground storage will figure more largely. Perhaps we shall have effective laws to guide orderly withdrawal and replenishment of ground water. The coming conflict between irrigation and municipal-industrial use in the East will require major changes in water law. Legal control of ground water seems almost inevitable in the East, as well as in the West, and I, for one, foresee (perhaps it is a mountain that looms far in the distance of the normal horizon circle) the dethronement of river transportation as the legally favored use in the East. Here is an anachronism which the late twentieth and the twenty-first centuries will surely shake off.

As a closer adjustment of water uses to resources is worked out, and particularly as industry with its steady day-by-day requirements nears perfect adjustment to the geographic distribution of water, the time variations in water will become increasingly important. Ours is an age that depends to an increasing degree on water storage in surface reservoirs, and such reservoirs all have a limited life. "Regulation [by reservoir storage] can never fully or permanently solve our water problems." It is impracticable in such areas as the lower Mississippi; where feasible, it is not permanent because reservoirs catch and hold the sediment brought to them, and reservoir sites are a limited, even a scarce, resource. Is it not likely that by the time industry has worked out a more nearly perfect adjustment to the geographical location of water resources, it will be cramped by steady decline in stored water? Will persons standing on the mountaintops of the distance look back to this as the extinct dam-building age? I cannot tell which figure I see in the distance: whether a declining water resource as the storage capacity to which water has become adjusted gradually fails; or well-managed watersheds which yield a minimum of silt, surface reservoirs that are truly conserved, a maximum use of sub-surface storage, and natural reservoirs along areas of chronic flooding.

In contrast to this uncertainty, I feel sure of one figure on the horizon: the regional management of waters by river basins and ground water basins, individually and in combination. A few years ago one might have assumed that this would come during the next few decades. But cooperation is a difficult pattern to learn; the requisite water knowledge for action would appear to be inadequate; and, in my opinion, some of the theorists on river basin management have gone astray. Some of the friends and practitioners of valley development have set the movement back by burdening it too heavily with assumptions that are highly debatable and with purposes realizable by other means. If the theory of river basin development can be freed from the outmoded assumption of the need for inland river and barge transportation and if the concern for "balanced regional economy" and "regional self-sufficiency" can be pared away (that is, if the planning of river basins is more closely limited to *water* planning for *essential* uses), it can, and, as I see it, it must provide the necessary regional organization in water management. Without river and ground water basin management, the most efficient use of water cannot be achieved, nor can adequate supplies for industry be guaranteed for the more remote future.

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Discussion

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The contributions from engineers, geographers, and hydrologists leave some doubt as to whether or not adequate supplies of water will be available in the right place for industry as it expands in the next two decades. Doubt arises not so much from evidence that is in conflict or is validated as from the lack of evidence on certain aspects of future supply and use.

On most points there seems to be substantial agreement: industry promises to expand; the consumption of water also promises to expand; there is no widespread current shortage of supply; there are scattered shortages which are distinctly local in character and which for the most part are transitory until new facilities are constructed; no major trends in total volume of supply may be discerned; the basic hydrologic data are inadequate for many forecasts, particularly in small drainage areas; more attention must be given to abatement of pollution of present supplies if future needs are to be met. All this suggests that in terms of physical limits of supply—both surface and underground—the problem of satisfying future needs is neither insoluble nor discouraging.

Yet the papers call attention to at least four questions for which there are no clear answers and which might affect profoundly the long-run solution of the problem. These questions relate to the permanency of the surface storage, to the tech-

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nology of water use in industry, to the relative values of cost factors affecting industrial location, and to the flexibility of political institutions controlling water rights, water use, and water misuse.

Because a large proportion of industrial water now comes from surface storage and because future increase in availability of surface supplies will hinge in most instances upon regulating flow by new storage, Whitaker's query as to the permanency of our storage reservoirs is a basic one. In some parts of the United States, such as the Tennessee Valley, present data on reservoir silting indicate that the utility of the reservoirs will not be affected significantly for at least several hundred years. In other areas, such as the Colorado Basin, the rate of silting is so rapid that a life of two hundred years is predicted for some reservoir systems and that large portions of certain reservoirs are to be dedicated to silt storage. We do not understand the complex factors of silting sufficiently to be warranted in predicting the course of reservoir filling in all drainage areas or the extent to which silting may be halted or retarded by land-management practices. Until our understanding is deepened in this area of knowledge, estimates of future surface supply must remain tentative.

In making estimates of future water demand it has been common practice to assume that the expanding use of water by industry would aggravate rather than alleviate the present supply-demand situation. Hudson's analysis shows the possibility of actually reducing the consumption of water at the same time that manufacturing production increases. This can be done by applying the technology already available in large measure. Endowed with very large and cheap resources of water, Americans have, as Powell and Knoedler point out, tended to neglect means of minimizing consumptive use. Here the need clearly is for intensive studies on a basin-wide basis in which industrial management would take a leading role in supplementing the studies that are going forward on sources of supply and on pollution abatement. One reason that such studies of more efficient use have not been widespread is that industry, by and large, still finds water a cheap material.

Probably there is less precise evidence on the question of costs than on any other question reviewed in this symposium. Southern California has demonstrated the economic practicability of using water long distances from where it occurs in nature. General references are made to industries having trouble finding sufficient water, but there are few specific instances of a company changing a prospective location because of water supply. At the Mid-Century Conference on Resources, Abel Wolman noted the lack of concrete cases of such shortage. Studies of water use and of plant location have not yet yielded enough data to justify generalizations. It may be, for example, that the major industrial users of water could stand very large proportionate increases in the cost of water without serious consequences, and that cost increases would have to be substantial before control, recycling, and similar measures would become economically feasible. The rate of equipment replacement would be an important factor. It is misleading to appraise the water situation without regard to the relation of water costs to other costs of manufacturing, and our knowledge of that relation is at best sparse.

Much of what has been said as to both studies and action assumes a wise application by public agencies of the knowledge that already is available. Collection of basic data, stimulation of research, the making of basin-wide studies, the fostering or requirement of control measures by water users, and the recognition of water rights for new uses—all must be based upon the revision of federal or state agency procedure, upon government appropriations, and upon development of new, cooperative agencies to prepare basin programs. Here there seems greatest ground for pessimism. The record of the United States in planning for basin-wide programs for navigation, irrigation, flood control, and hydroelectric power is not encouraging. Both organization and law are slow to change to care for unfolding needs. The great demand for ingenuity and determination in solving the problem of future industrial water supply will be in readjusting the political structure and process so as to reduce the areas of ignorance and to apply what already is known. Widespread and persistent failure to make these readjustments could lead to widespread and unnecessary shortages just as local failures already have led to local shortages.

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Water supply is becoming increasingly critical, not because the resource is being excessively depleted, but because water-developing facilities are not being expanded to meet increased water demands. In order to protect our expanding industrial economy we must take action that will decrease or eliminate water shortages.

Appraising our water resources and maintaining current records of their change in quantity and quality are primarily functions of government at all levels, federal, state, and local. The development and control of our water resources to insure their optimum use on the one hand and to minimize their destructive powers, on the other was at one time the primary concern of the user. However, as the economy has grown, development and control of water have become increasingly important to the people as a whole and, hence, government has come to share the responsibility for development and control with private individuals and with industry.

Most water resources activities are of national interest; therefore, the Federal Government should take part of the responsibility and very often it should take the initiative. On the other hand, some activities are of only state or local interest and, therefore, the initiative should be taken at the state or local level.

The responsibility for water resources at the federal level is shared by several departments. The Department of the Interior, through the Geological Survey, collects data on the quantity and quality of our water resources. The Bureau of Reclamation develops water supplies for irrigation. The Corps of Engineers constructs flood protection works. The Department of Agriculture develops soil and water conservation practices and assists in the application of these practices. The Health, Education, and Welfare Department has a major interest in control of water pollution because of the importance of clean water to national health.

Several activities of the Department of the Interior are related to water for industry. The Geological Survey is collecting and publishing basic data on the quantity and chemical quality of our ground water and surface water resources, and on the chemical quality of public water supplies. In addition, the Survey is preparing reports on the water resources of selected industrial areas. These reports were designed primarily to meet the planning needs of defense agencies; however, they are equally applicable to the needs of industry and local governments. The Geological Survey also prepared a report on the water requirements of the pulp and paper industry, one of the large users of water. Other reports in this series are in preparation. There appears to be an increasing interest, and certainly an increasing need, for reports of this type.

The Department of the Interior is also charged with leadership in research on the conversion of saline water to fresh water. This activity is coordinated by the Saline Water Conversion Program.

The action that should be taken has been indicated by administrative policy announcements, the President's Materials Policy Commission, the Mid-Century Conference on Resources for the Future, and House Document 706, Eighty-first Congress, second session, a program to strengthen the scientific foundation in natural resources. All are agreed that we need more detailed hydrologic information and a greater understanding by the public of both the problem and the requirements for solution of the problem. The public must understand that the wise use and conservation of our water resources depend upon developing inventories, long-range programming, and creating administrative and fiscal means for converting plans and programs into structures. It must also understand that proper development of water resources requires planning well in advance of the demand.

Index